To carry out fire and rescue operations in the best possible way it is important to be well-informed. In the case of fire and rescue operations involving buildings, knowledge concerning smoke, the spread of smoke, pressure conditions and ventilation measures can often be decisive for the results of the operation.

Fire ventilation combines experience from fire and rescue services and research in the form of experiments and theoretical studies on the subject. In this book there is a description of the fundamental principles for fire ventilation and the spread of smoke, how fire ventilation should be implemented, positive pressure ventilation, and which opportunities and problems can be encountered in association with creating openings in different types of structures.The book provides examples of fire fighting situations and there is also a general reasoning on tactics during fire ventilation.

The book is primarily intended for the Swedish Rescue Services Agency's training activities, but is also addressed to professional fire and rescue personnel and other interested parties.

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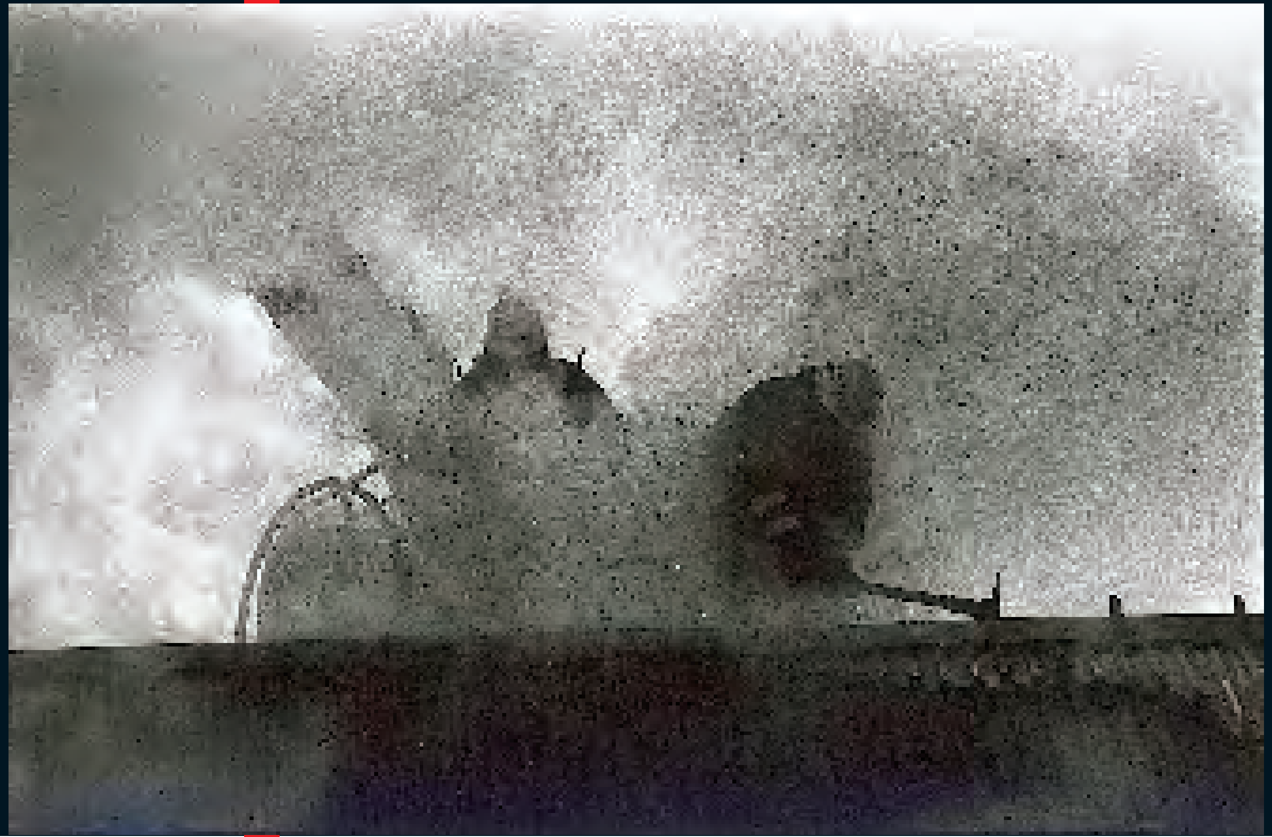
Fire Ventilation

Swedish Rescue Services Agency

Stefan Svensson

Fire Ventilation



Stefan Svensson works as a research and development engineer/instructor at the Swedish Rescue Services Agency. He started his career as a fire fighter in the Swedish Air Force in 1986, became a fire protection engineer in 1989 and earned his Ph.D. in 2002. Stefan is researching on the subject of fire fighting tactics. He has also worked for a number of years on fire ventilation, and has contributed to several works on manual high-pressure fire fighting.

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Contents

Foreword

In this book fire ventilation is understood to refer to all the measures taken by fire and rescue services during fires, above all in buildings, to release fire or hot gases into the open. Salvage and overhaul, which can be a positive secondary effect of fire ventilation, has not been taken into consideration. Permanent arrangements in buildings in the form of vents or fans, for example, have only been treated in general terms.

The book is primarily intended for the training activities of the Swedish Rescue Services Agency. Chapters 1-4 include theoretical concepts of fire ventilation, the fundamental principles for fire gases, pressure and temperature conditions in buildings. The book also describes how fire ventilation ought to be implemented in practice, which problems and opportunities can be expected when creating openings in different types of structures, and the essentials of positive pressure ventilation (chapters 5-8). In chapter 9 there is a general reasoning on tactics during fire ventilation. The final chapter in the book presents examples of fire fighting situations.

The book is based on practical experience from fire and rescue services, research and experiments, and on the available theoretical knowledge on the subject. The book does not claim to be fully comprehensive, since there are many variations of fire ventilation. For those who wish to undertake further reading there is a list of recommended literature at the end of the book.

Major contributors to the book include Sören Lundström, the Swedish Rescue Services Agency, Lasse Bengtsson, Helsingborg Fire Department, and Magnus Nygren, Swedish Rescue Services Agency. Bertil Wildt-Persson, Norrköping Fire Department, has also been a great source of inspiration.

Foreword to the English edition

This book is mainly based on Swedish conditions and has primarily been written for Swedish fire fighting crews. The structure of buildings, how the rescue services are organised and the technical solutions have therefore been described on the basis of how we do it in Sweden. Nevertheless the basic principles concerning the spread of smoke, for example, are obviously exactly the same regardless of where one is in the world. Note also that most of the titles in the section "For further reading" are in Swedish. The Swedish edition of this book was issued in 2000 and because of circumstances beyond my control has unfortunately not been translated to English until now. Neither has it been translated by me personally, but I hope the reader can overlook this and will find the book interesting and rewarding.

Stefan Svensson

CHAPTER 1

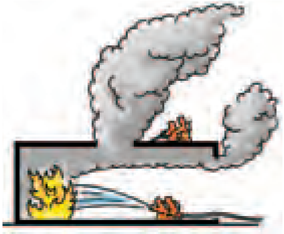
Fire ventilation

The fundamental principle of fire ventilation is to actively attempt to change the pressure conditions prevailing in a burning building with a view to releasing fire gases. The work methods, the choice of them, and the tactical structure of the fire and rescue operation depend on the objective and purpose of the measures.

Objective and purpose of gas ventilation

The objective of fire ventilation is to release heat and fire gases into the open. Depending on the type, configuration and implementation of the operation, this serves several purposes. We use fire ventilation to:

- Reduce the impact of fire gases and heat on trapped persons, and to facilitate their evacuation from the building.
- Facilitate the fire and rescue operation by reducing the thermal load, and to improve visibility in the building for the fire fighting crew.
- Prevent or contain the spread of fire or fire gases through a reduction of the impact of pressure and heat in the building.
- Enable or facilitate salvage and overhaul at an early stage of the fire and rescue operation.



Fire ventilation can have several purposes, for example to reduce the effect of smoke and heat on trapped people and to improve working conditions for the fire fighting crew.

Openings and fire ventilation

It is very often possible to utilise existing openings such as doors, windows or vents for the purpose of ventilation. But openings are also made in structures for the purpose of fire

Fire ventilation. 90 seconds have gone between the two illustrations. (Images from video film.)

ventilation, for example openings can be made in the roof.

Fans are also used on various occasions. This would imply that fire ventilation is not always a clearly defined task, and that focusing on the implementation of such a measure can therefore be misleading. For this reason a clarification of the different implications of the measure can be in order.

Openings can be made on the basis of the following initial conditions, which can all be described as fire ventilation:

Opening and ventilation of room exposed to fire.

Venting of a room exposed to fire

This is the type of operation normally associated with the concept of fire ventilation.

Venting of adjacent rooms.

Venting of adjacent rooms

This is often done in connection with separations or conceivable lines of containment. This type of fire ventilation can fulfil at least two functions:

1. Reduce the impact of heat and pressure on the structure and adjacent room.
2. Physically separate the structure so that fire and fire gases cannot spread.

Openings to gain access to a fire that has spread into the structure, for example in the walls or floor structure

This resembles and is therefore often confused with "venting of a room exposed to fire" and "venting of adjacent rooms". It is often implemented in connection with roof fires, or fires in concealed spaces that cannot be reached in any other way. The intention is in the first instance to gain access to and suppress the fire inside the structure, not to vent out smoke.

Opening to suppress or prevent fire spreading in walls or floor structures.

Venting for mopping up/salvage and overhaul

There is often a thin line between a fire and rescue operation and salvage and overhaul. Salvage and overhaul is often started long before the fire and rescue operation has been completed in the legal sense. Salvage and overhaul is not considered in any greater detail, however, in this book.

All these initial conditions fall under the collective concept of fire ventilation, since in the course of the practical work in fire and rescue operations they bear similarities or are implemented side by side with each other in various

A hatch in the roof or a skylight can be used for vertical fire ventilation.

ways. There are, however, significant differences between them in terms of what is to be achieved by the measure in question and how the fire is affected, which in turn affects the continuation of the operation.

Implementation of fire ventilation

Fire ventilation can be implemented in three different ways, among other things depending on the relative configuration of inlets (openings where fresh air flows in) and outlets (openings where fire gases flows out), both in terms of distance and height, and also depending on which other resources are used:

Horizontal fire ventilation

This is where the outlets are on the same level as the fire, so that the flow of fire gases takes place horizontally. This

Top left: a window in the fire room can be used for horizontal fire ventilation.

Top right: fans can be used to achieve mechanical fire ventilation.

would be the case, for example, in apartment fires or in certain types of industrial buildings where it is difficult, or in fact impossible, to create openings in the roof and where there are no skylights or vents.

Vertical fire ventilation

This is where the outlets are above the fire, often as high as possible in the building so that the flow of fire gases takes place vertically. The outlet is normally implemented by making an opening in the roof structure, or by using existing vents (windows/apertures or vents/shutters).

Mechanical fire ventilation

This can mainly be implemented as positive pressure ventilation or negative pressure ventilation. The mechanical ventilation must be combined with creating openings, so as to achieve horizontal or vertical ventilation.

Fundamental principles

Fire ventilation influences a fire by supplying more air, whereby the intensity of the fire increases. Conversely this of course means that a fire can in certain cases be contained if there is no fire ventilation. Nevertheless fire ventilation seldom has a negative effect on the results of a fire and rescue operation seen as a whole, on the assumption that the ventilation measures are coordinated with other measures, such as for example suppression. Fire ventilation may aggravate the situation for a time, but also makes it possible to influence the fire in such a way that any problems can be brought under control. In all likelihood other and more severe problems would occur if fire ventilation had not been implemented at all. Fire ventilation should, however, be implemented in the right way, at the right place, and at the right time, and be coordinated with other measures, above all extinguishing.

It is often of critical importance for the results of fire ventilation whether the fire is fuel controlled or ventilation controlled when the measure is implemented. A fuel-controlled fire is essentially controlled by the amount of fuel and how the fuel is positioned, while a ventilation-controlled fire is essentially controlled by how much air the fire has access to. If fire ventilation can be implemented at an early stage of the fire scenario, i.e. when the fire is still fuel controlled, this can prevent or at least delay ventilation control. It would be the same thing to say that very often a fully developed fire can be avoided, or at least delayed. Combined with powerful and rapid suppression measures, this

Fire ventilation should be implemented as soon as possible during the fire and rescue operation.

It is often of critical importance for the outcome whether the fire is fuel controlled or ventilation controlled, along with the coordination of other measures.

results in quicker and more simple extinguishing. The spread of the fire can be more easily prevented and therefore the damage caused by the fire can be better contained.

Fire ventilation at a later stage, when the fire is ventilation controlled, often means that it is more difficult to implement internal suppression. In closed areas the fire scenario can accelerate violently when air gains access to the fire as a result of fire ventilation, in particular if the fire has been underway for a prolonged period in the closed area. The intensity of the fire can increase, the fire spreads more quickly, more fire gases is formed, and the fire becomes more unpredictable. If the fire rapidly becomes fully developed it can be more difficult to penetrate into the fire room. The impact of the heat increases both on the enclosing structures and on the fire fighters. There is also an increase in the production of fire gases, which can spread the fire. Fire ventilation of areas with fully developed fires has a limited effect. It can therefore be wise to vent adjacent rooms where the damage is not so serious.

Fire ventilation should be implemented as soon as possible during the fire and rescue operation. If the fire is fully developed in one or more rooms, it is very often better to focus on fire ventilation of the adjacent rooms where the fire has not yet spread.

Extreme caution is required in the case of ventilation-controlled fires in very large or inaccessible rooms. Above all it is necessary to coordinate with other measures being taken at the scene of accident, in particular the suppression measures. In all probability the fire will increase in intensity after implementing fire ventilation. If air is supplied to a ventilation-controlled fire the worst scenario can be a fire gas explosion, or a backdraft.

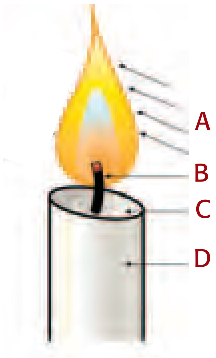
Fire gas explosion
When unburnt gases from an under-ventilated fire flow through leakages into a closed space connected to the fire room, the gases there can mix very well with air to form a combustible gas mixture. If these gases are ignited, a fire gas explosion may occur.

Backdraft
Backdraft is the burning of heated gaseous products of combustion when oxygen is introduced into an environment that has a depleted supply of oxygen due to fire. This burning often occurs with explosive force.

CHAPTER 2

Fire behaviour

Heat, fuel and air are necessary for fires to start and continue to burn. Normally in the case of fires in buildings the fuel is separate, for example in the form of a television or a sofa, and the air is also separate (if we disregard the air in the upholstery). The fuel and the air are not mixed until during the actual combustion, or just before. The type of flame in this situation is called a diffusion flame, and a good example of this is the flame on a normal candle. The fuel (the stearin) melts, is transported up through the wick, and gasifies. Air presses in towards the fuel from the sides, i.e. the surrounding air, and fuel in the form of gasified stearin diffuses into the combustion zone. Combustion takes place in the interface between the fuel and the oxygen, i.e. in the combustion zone.



The flame from a candle is an example of a diffusion flame.
A. Air (oxygen) diffuses into the flame and reacts with gaseous fuel.
B. Transport and vaporisation of fuel in the wick
C. Liquid fuel
D. Stearin (solid fuel) in solid state.

A fire in a building or in a room is generally characterized by four phases, which taken together constitute the fire behavior in a building or in a room.

1. The initial stage of the fire, ignition and growth (pre-flashover)
2. Flashover
3. The fully developed fire (post-flashover)
4. The cooling phase (decay)

In the initial stage of the fire only one or a few objects will be burning, for example a television or a sofa (the so-called initial fire, i.e. the first fire in the room). Fire gases are formed by the fire, rise upwards, and forms a hot layer of fire gases close to the ceiling. This grows in volume and becomes hotter and hotter as more fire gases are supplied. This part of the scenario is relatively calm and undramatic.

Pyrolysis
Irreversible chemical decomposition of a material due to heat.

Flashover
During an enclosure fire a stage can be reached where the thermal radiation from the fire, the hot gases and the hot enclosing surfaces cause all the combustible surfaces in the fire room to pyrolyse. Sudden transition to a state of total surface involvement in a fire of combustible materials within a compartment.

It is often possible to stay in the room without any major problems, and the fire is relatively easy to put out with a hand-held fire extinguisher, a blanket or a rug etc.

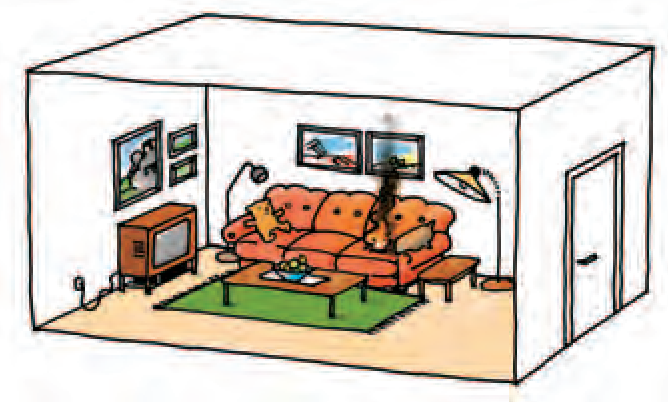
Gradually, however, it becomes impossible to stay in the room because of the fire gases and the heat. The fire and the hot gases emit thermal radiation in the immediate vicinity of the fire and in the rest of the room, which causes the fire to subsequently increase in size at an ever increasing rate.

When the initial fire has developed to such an extent that the ceiling, walls, floor and interior furnishings in the room have reached a certain temperature, what is called a flashover takes place. The flashover is the transitional stage between the initial stage of the fire and the fully developed fire. In this stage the fire changes from continuing to burn in one or a few separate objects to envelop, in a few seconds, all the objects and surfaces in the room. The whole room becomes engulfed in flames. One prerequisite for this to happen, however, is that there is sufficient air in the room, or that a sufficient amount of air is supplied to the room. Otherwise there will be no flashover and the fire will diminish in intensity, and become ventilation controlled.

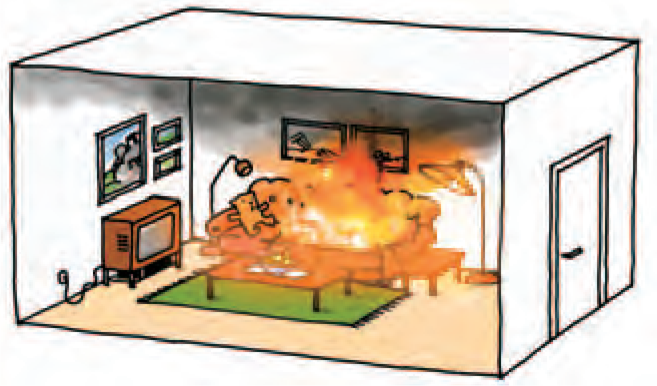
Flashover results in a fully developed fire. The flames rush out through openings and the heat has a powerful effect on the surrounding structures, through radiation and convection (transport of heat through movements in the air) and through conduction (transport of heat inside materials). The risk of the fire spreading to adjoining rooms or buildings is imminent at this stage. The fire also has a powerful effect on the surrounding structure.

When the fuel begins to be used up, the fire starts to subside. It enters into its cooling phase and the temperature gradually drops.

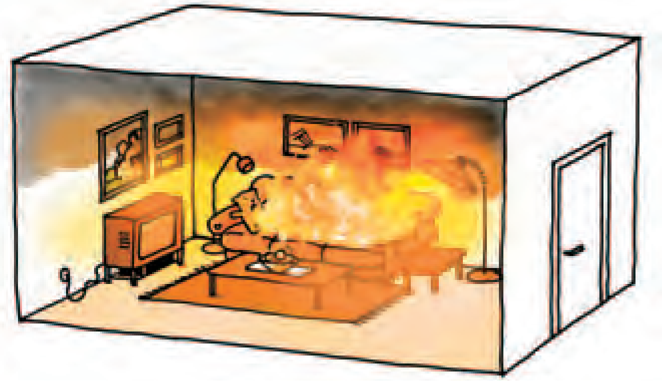
The intensity of the fire is determined by the volume of the fuel and the air, and the ratio between these two components. The fire can therefore be characterised on the basis of its access to air. A fire that burns with a deficit of air, for example in a closed room or a room with small openings, is called a ventilation-controlled fire. If it is sufficiently hot in



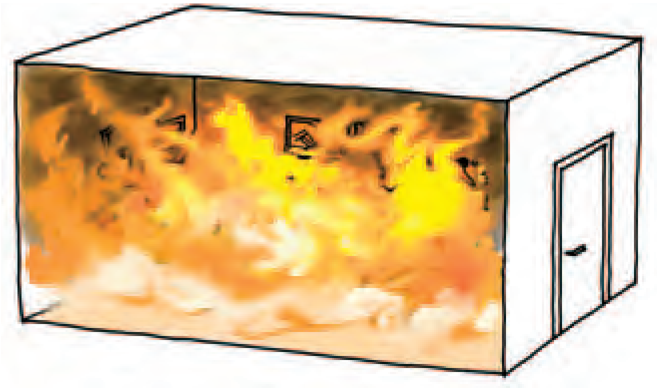
The initial fire is often small at first, and can be difficult to detect.



As the fire grows more and more hot gases are formed, which rise upwards and fill the upper part of the room.



After several minutes the smoke can be very hot, and it then contributes towards heating up the walls and ceiling in the room.



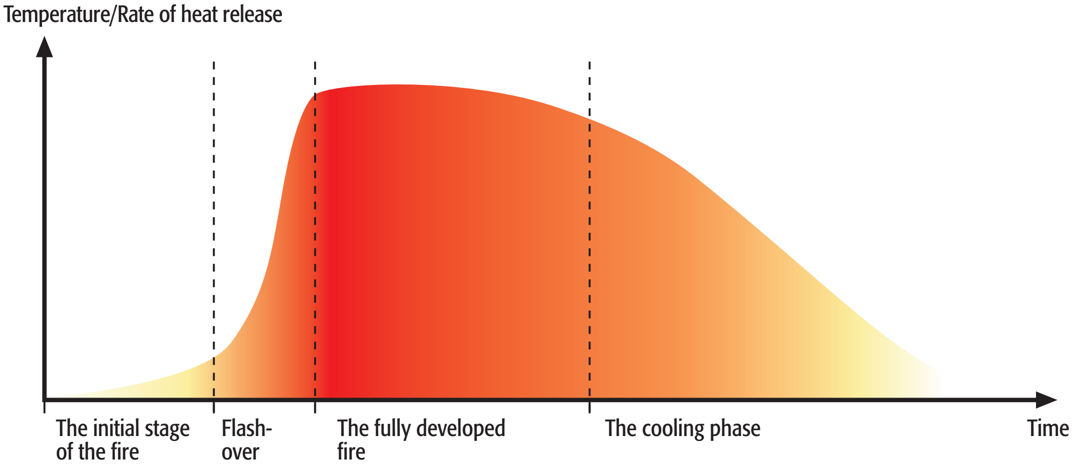
If there is sufficient air in the room all the objects in the room will be heated up to such an extent that the entire room can eventually be ignited during a relatively short period. This transition period is called flashover.

Flashover results in a fully developed fire.

the room more pyrolytic gases, i.e. combustible gases, will be produced than what the fire can consume. These gases are contained in the room. If a door is opened more air will be supplied to the fire, more fuel can then be combusted (burn), and the intensity of the fire will increase. In certain conditions the uncombusted gases that have collected can be ignited and start to burn, either outside or in the room, or both inside and outside the room.

A fire that burns with a surplus of air, for example in the open or in a room with very large openings, is called a fuel-controlled fire. Additional openings (for example if a door is opened) will not noticeably increase the combustion, and

The result of fire ventilation depends to a large extent on whether the fire is ventilation controlled or fuel controlled when the measure is implemented.



The temperature and development of the intensity during a complete fire scenario.

therefore neither will they influence the intensity of the fire.

In the initial stage of a fire the fire is normally fuel controlled, while the fully developed fire is normally ventilation controlled. The flashover is therefore the transition stage from fuel control to ventilation control. What can often happen during fire ventilation is that the conditions change from ventilation control to fuel control, or from a stage with powerful ventilation control to a stage with not so fully developed ventilation control.

CHAPTER 3

Fire gases

Fire gases is a mixture of hot air, particles, combustible gases (for example carbon monoxide) and incombustible gases (for example carbon dioxide) that are formed during combustion. The composition is determined among other things by the conditions prevailing at the fire. It can be changed in conjunction with fire ventilation, i.e. during changes in the supply of air to the fire.

Different combustion products are formed depending on the ratio between the two components, the fuel and the air.

As a rule the combustion is incomplete, especially during normal fires in buildings. In which case, combustion products are formed that are flammable to a greater or lesser degree, and which therefore can burn under certain conditions. These combustion products follow along with the rest of the fire gases and collects in a hot upper layer.

The fire gases formed during fires consists of two components. The absolutely largest component consists of the air that is mixed with the combustion products from the fire, heated up by the fire, and which is relatively unaffected by the chemical reactions taking place in the fire.

The second component consists of the decomposition and reaction products formed during the fire, including gases such as carbon dioxide, carbon monoxide, water vapour and methane, and particles in solid form (soot) or in liquid form (for example heavier hydrocarbon compounds). This component is very small in terms of both weight and volume. The volume of fire gases formed is therefore basically the same as the volume of the air mixed into the plume of fire, heated up and expanded. The physical properties of fire gases are therefore more or less the same as for air, for which reason the flow of fire gases is treated as a flow of heated air both during calculations and for tactical assessments of fires. The flow conditions will not be affected even if there is a powerful development of fire gases that contains a large number of particles, and which therefore has low transparency.

Nevertheless, the chemical properties of fire gases can differ significantly from air, for example in terms of reactivity, combustibility or toxicity. The particles in fire gases can be very irritating for the eyes, mucous membranes and the respiratory channels.

Even during small apartment fires a large amount of fire

Reactivity
Substances have different capacities to react chemically with other substances. For example, the metal sodium reacts violently with water during the powerful development of heat and hydrogen gas. On the other hand sodium does not react with paraffin at all. Substances that react easily with other substances are said to have a high reactivity.

Combustibility
A substance's combustivity describes how combustible it is, i.e. how easily it sets on fire and burns.

Fire ventilation can change the conditions prevailing during a fire in such a way that incompletely combusted products are ignited.

Fire gases contains products such as carbon monoxide, carbon dioxide and hydrogen cyanide. Therefore they are in most cases very toxic to humans.

gases is produced that contains incompletely combusted products, and which are combustible to a greater or lesser degree. Under certain conditions these combustion products can be ignited, for example if the temperature is sufficiently high, if there is an adequate supply of air to the fire gases, or above all if the volume of combustion products exceeds a certain limit. Fire ventilation can change the conditions prevailing during a fire in such a way that incompletely combusted products are ignited. This can lead to a rapid and uncontrolled spread of the fire.

Toxicity
Substances are toxic to varying degrees. For example, pure water is not toxic at all, while petrol is poisonous for human beings. The toxicity describes how poisonous a specific substance is.

Fire gases can be treated as hot air during tactical assessments. Consideration must, however, be taken to the combustibility and toxicity of the gases.

If the fire gases contains a sufficient amount of uncombusted products and if the temperature is sufficiently high, the supply of air that normally takes place during fire ventilation can lead to the ignition of the fire gases.


Tobak

CHAPTER 4

The spread of fire gases

The flow of fire gases always takes place from higher to lower pressure. The magnitude of the difference between the higher and the lower pressure determines the size of the flow, and how quickly this flow takes place. The magnitude of the pressure difference is in turn determined by the size of the openings between rooms, the wind conditions, the size of the fire and how it develops, and the ventilation system etc. Differences in pressure can cause fire gases and the fire to spread long distances, and in directions that cannot always easily be predicted. With a knowledge of the different types of pressure differences in buildings and how they arise, the spread of fire gases can to a certain degree be predicted, and in certain cases also prevented. Sometimes it is in fact possible to change the direction of the fire gases, and to steer it through and out from a building. It can, however, be very difficult to produce an overall view of what the pressure differences look like inside buildings.

Pressure differences in buildings

It is relatively well known how the build up of pressure takes place and how fire gases spreads in a room that is burning, but when a complete building is affected by the fire the problem becomes somewhat more complex. When a fire is in progress it is seldom, or never possible to make a more extensive analysis of the pressure differences and their causes, but it is important to have a certain understanding of what it is that influences the spread of fire gases in a building and out from the building.

The dynamic pressure differences can be divided up into two categories: normal pressure differences that always exist in a building or between a building and its surroundings, and pressure differences created by the fire.

Normal pressure differences

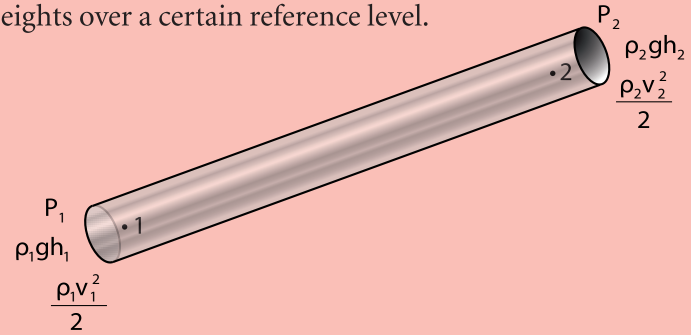
- differences in temperature between outdoor and indoor air
- the effect of the wind
- comfort ventilation (mechanical ventilation and natural ventilation)

Pressure differences created by the fire

- inhibited thermal expansion
- thermal buoyancy force

Bernoulli's equation

Bernoulli's equation describes the relationship between the pressure, flow and speed of a flow. The equation is also of fundamental importance for the calculation and assessment of the spread of fire gas.
Consider a pipe with a flowing gas, where the ends of the pipe are at different heights over a certain reference level.



The atmospheric pressure is designated as P, the density as ρ, the height over a certain reference level is h, the speed is designated as v, and the gravitational constant as g ($\approx$9.81 m/s^2). The hydrostatic pressure, i.e. the pressure resulting from the ambient gas, at point 1 and point 2, will therefore be:

$\rho g h$

The hydrodynamic pressure, i.e. the pressure resulting from the flow of the gas, at point 1 and point 2, will therefore be:

$$\frac{\rho v^2}{2}$$

The first law of thermodynamics (the principle of the conservation of energy) says that:

$$P_1 + \rho_1 g h_1 + \frac{\rho_1 v_1^2}{2} = P_2 + \rho_2 g h_2 + \frac{\rho_2 v_2^2}{2}$$

With the help of Bernoulli's equation it is possible to derive and analyse what the pressure structure looks like in a building, and accordingly also how the fire gases will flow.

In what follows these pressure differences will be treated separately. In actual fact several or indeed all of these different types of pressure differences will arise and act simultaneously, for which reason a more simple line of reasoning around the problem will be left to the end of the chapter.

Differences in temperature between outdoor and indoor air

The air indoors is most often warmer than the air outdoors. Air that is heated up expands, takes up more space, and has a lower density than cold air. The pressure inside a building, where the air is warmer than outside, will therefore be higher than outside. This pressure strives towards equilibrium with the surroundings, and therefore the heated air flows out from the building; from the higher pressure inside the building to the lower pressure outside the building. Since a building is seldom or never completely tight, the (heated) air will always be forced out from the building and, at least gradually, be replaced by cold air flowing in. If the openings are small, or if the pressure difference is large in relation to the size of the

Pascal
Pressure is measured in the international unit Pascal [Pa]. 1 Pa is the same as 1 N/m^2 (1 Newton per square metre) or 10^{-5} bar (0.00001 or ten million parts per bar). 1 Pa is approximately equivalent to the pressure a standard A4 sheet of paper exerts on the surface of the table. The normal air pressure is 101325 Pa.

openings, this flow will take place through different openings. The inflow takes place through one opening, and the outflow through another. If the openings are large, or if the pressure difference is small in relation to the size of the openings, the flow can take place through the same opening.

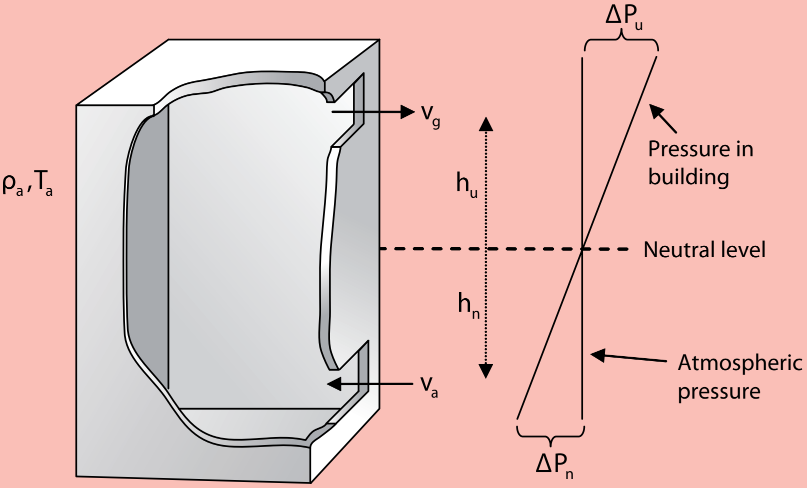
In addition hot air rises upwards, which normally causes the outflow to take place through openings situated high up and the inflow through openings situated much lower down. This also means that the pressure difference in relation to the surroundings will be highest at the top of the building and lowest at the bottom. In low buildings, or in one and the same floor, these pressure differences are often negligible, while in high buildings they can be very large. This can be the case in high-rise buildings with several floors, but also applies to warehouse buildings or industrial workshops with high ceilings. An upward moving air flow is created in the vertical shafts etc. of high buildings. If it is warmer outside than inside the conditions can be the reverse, and the flow of air will go downwards instead.

Pressure differences produced by differences in temperature between the building and its surroundings are normally in the magnitude of ten or a few tens Pascal.

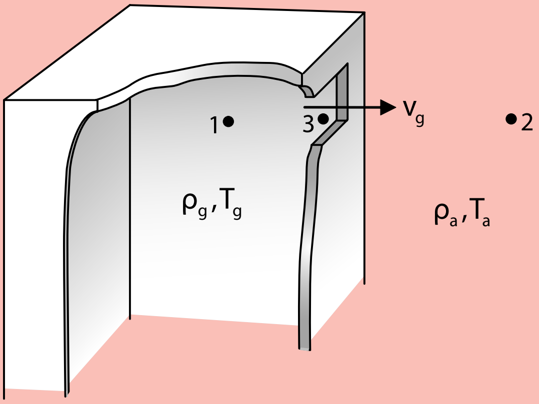
In buildings with openings both at the top and the bottom a so-called neutral level will be formed at the height where the pressure inside the building is the same as outside the building. If the air inside the building is heated up and becomes hotter than the air outside, air will flow out from the building over the neutral level and into the building below the neutral level.

Pressure in building

Let us look at a building that has one room, with one opening up by the roof and one opening down by the floor. Assume that the air that flows into the building is heated up in some way. The ambient air has a temperature of T_a and a density of ρ_a, and the air in the building has a temperature of T_g and a density of ρ_a. The upper opening is at a height of h_u over the neutral level, i.e. where the pressure in the building is the same as the pressure outside. The lower opening is at a height of h_n below the neutral level.



We want to know how large the pressure difference is over the respective openings, ΔP_u and ΔP_n.



We simplify the problem by only studying the points 1, 2 and 3 in the upper part of the building. The hydrostatic pressure difference between point 1 and point 2 is:

$v_1 = v_2 = 0$

$P_1 - P_2 = \rho_2 g h_2 - \rho_1 g h_1$

$\Delta P_u = h_u g (\rho_a - \rho_g)$ **Equation 1**

The hydrodynamic pressure difference between point 1 and point 3 is:

$v_1 = 0$ $\rho_1 = \rho_3 = \rho_g$ $h_1 = h_3 = h_u$

$$P_1 - P_3 = \frac{\rho_3 v_3^2}{2}$$

$$\Delta P_u = \frac{\rho_g v_g^2}{2}$$

Equation 2

We can obtain the speed through the upper opening by using the equations 1 and 2:

$$\frac{\rho_g v_g^2}{2} = h_u\, g\, (\rho_a - \rho_g)$$

$$v_g = \sqrt{\frac{2 h_u g (\rho_a - \rho_g)}{\rho_g}}$$

Equation 3

The relationship between temperature and density is given by the gas law, and we can use this to determine the relationship between the density and temperature. At normal atmospheric pressure we obtain the relationship:

$\rho P M = RT$	gas law
$P = 101.3$ kPa	normal atmospheric pressure
$M = 0.0289$ kg/mol	molar density for air
$R = 8.314$ J/Kmol	gas constant
$\rho = \frac{353}{T}$	relationship between density and temperature

The mass flow in the opening is given by $\dot{m} = C_d A v \rho$

By doing the same thing for the flow into the lower opening and equalising the obtained expression with equation 3, an expression is obtained for the position of the neutral plane in relation to the size of the openings:

$$\frac{h_n}{h_u} = \left[\frac{A_u}{A_n}\right]^2 \times \frac{\rho_g}{\rho_a}$$

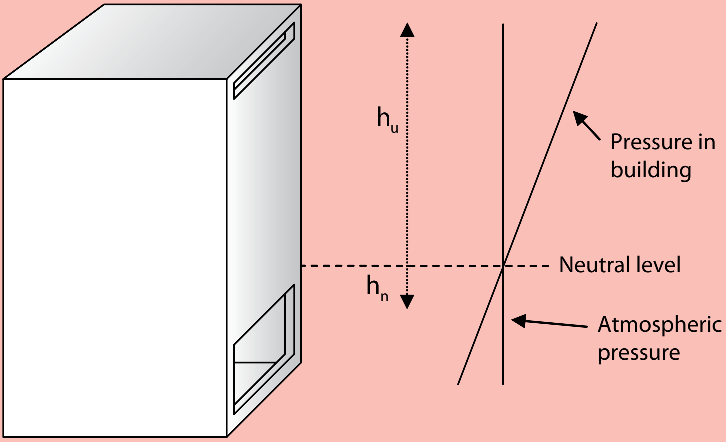
Equation 4

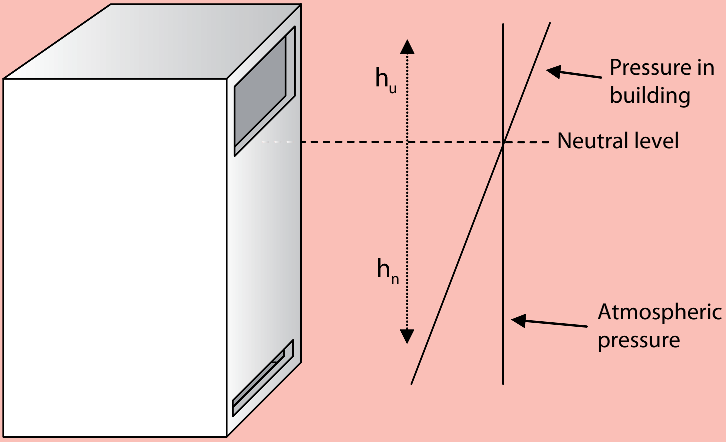
or, expressed in terms of temperature:

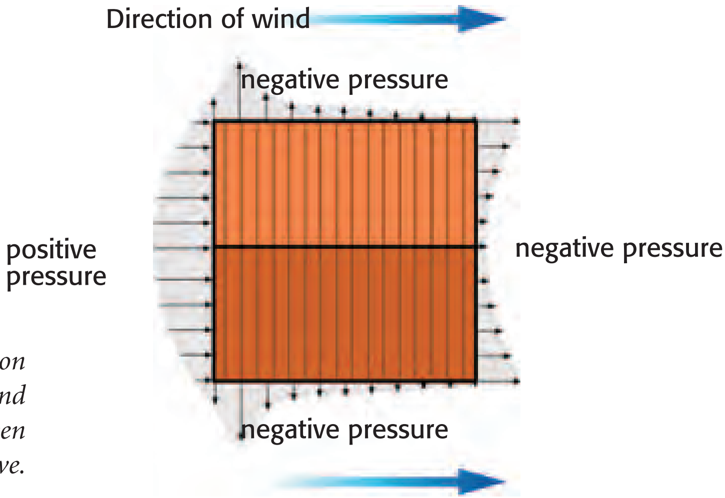
$$\frac{h_n}{h_u} = \left(\frac{A_u}{A_n}\right)^2 \times \frac{T_a}{T_g}$$

Equation 5

This means that if A_n is large in relation to A_u, then h_n will be small A_u, which will cause a large pressure difference over A_u. This is for example preferable in a chimney to achieve a good draught of funnel, but also in the case of only thermal fire ventilation. Equation 5 accordingly provides an indication of how the relationship between the size of the inlets and outlets should be, during only thermal buoyancy force. Note, however, that it must be the size of the outlet that determines the size of the inlet, and not the reverse. The need for an outlet, its size and location etc., must therefore be decided first.







The distribution of pressure round a building, seen from above.

The effect of the wind

All buildings allow in air to a greater or lesser degree, and in many cases the wind can have a very large effect on how fire gases flows inside a building.

The wind pressure is proportional to the square of the wind speed. This means that if the wind speed increases from 1 m/s to 10 m/s, the pressure on the wind side will increase from, for example, 0.4 Pa to 40 Pa, or from 0.6 Pa to 60 Pa (typical values).

Vertical surfaces (walls) normally produce positive pressure on the wind side (at right angles to the wind) and negative pressure on the leeward side (opposite/parallel

Calculation of the effect of the wind

The stationary pressure the wind exerts on a building can be expressed as

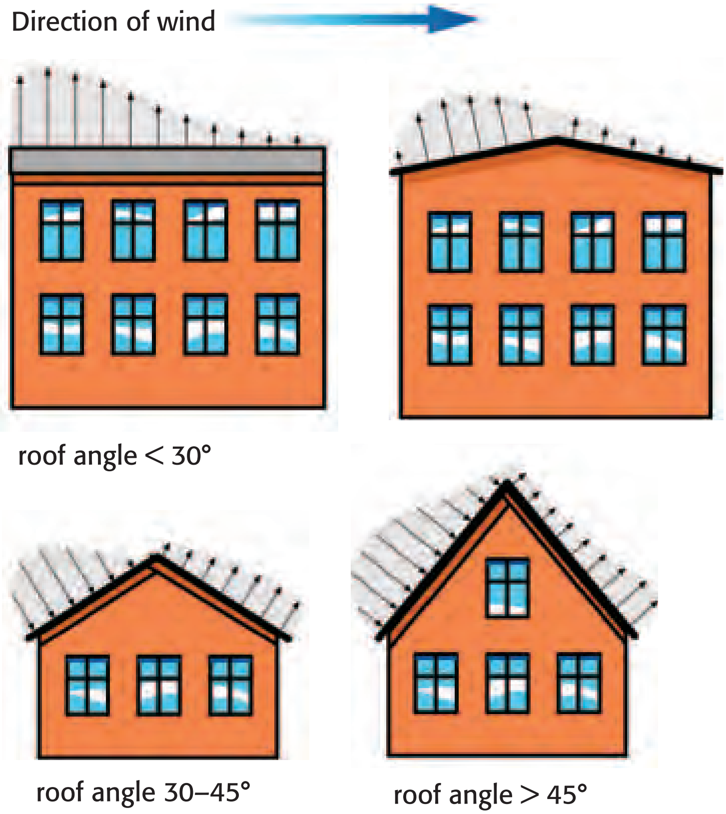
$$\Delta p = 0{,}5 \times c_f \times \rho_a \times v^2$$

where c_f is the form factor, ρ_a is the density of the outside air, and v is the wind speed. The form factor varies, partly depending on how the surface is in relation to the wind, and partly on what the building looks like. The form factor varies from 1 (corresponding to full positive pressure) to –1 (corresponding to full negative pressure). The form factor is mainly used to dimension buildings against wind loads, but it gives us an idea of how the wind creates pressure on and around a building.

side). The negative pressure on the leeward side is approximately half the pressure on the wind side. The pressure on roof surfaces exposed to wind depends on the angle of the roof. At angles of over 45° a positive pressure is created on the wind side, and a negative pressure on the leeward side. Both the positive pressure and the negative pressure are greatest at the respective bases of the roof, and diminish successively up towards the ridge. At roof angles between 30° and 45° there can, however, also be a negative pressure on the wind side closest to the ridge. At roof angles of less than 30° the entire roof is exposed to negative pressure. The negative pressure is highest on the wind side.

Gable roofs can be exposed to negative pressure along the entire surface, if the wind blows parallel to the ridge, regardless of the angle of the roof.

The differences in the pressure conditions that arise as a result of the roof angle can in certain cases be utilised to



The distribution of pressure over a flat roof. There is normally a negative pressure over the entire surface of the roof.

The distribution of pressure over a gable roof. The pressure varies from negative pressure to positive pressure, depending on the angle of the roof and where on the roof one is.

There can be very complex wind conditions round squares, parks, streets and buildings in the centre of a city.

make the effect of fire ventilation better than if only the thermal buoyancy force was used.

Fire ventilation through windows and doors (vertical outlets) can be better if they are made on the leeward side of the building, while inlets are made on the wind side. However, this sets stringent requirements that the openings are selected with care, and that the direction of the wind can be determined reliably. This is not always possible.

Because of friction with the ground surface the wind speed also varies, and thereby also the pressure, with the height. The friction varies in relation to the type of surface. The wind can behave completely different in and around built-up areas than it does in open terrain. It can be pressed together along streets so that wind speed is higher than expected, and in combination with the turbulence often created in built-up areas the wind can also take a comple-

On roof surfaces a positive pressure is generally created on the wind side, and a negative pressure on the leeward side. Flat roofs are exposed to negative pressure over the entire roof surface. Gable roofs can also be exposed to negative pressure along the entire surface, if the wind blows parallel to the ridge.

The wind can create very complex pressure structures round buildings in urban environments.
In and around buildings the wind normally gives rise to pressure differences in the magnitude of ten or a few tens Pascal.

tely different direction. Very complex wind conditions can also arise on open areas (squares and parks) where several streets converge.

Comfort ventilation

Comfort ventilation refers to the ventilation often used in buildings to let in fresh air and to ventilate out heat, residual products from our breathing (carbon dioxide), moisture and the smell of cooking. There are two types of comfort ventilation systems:

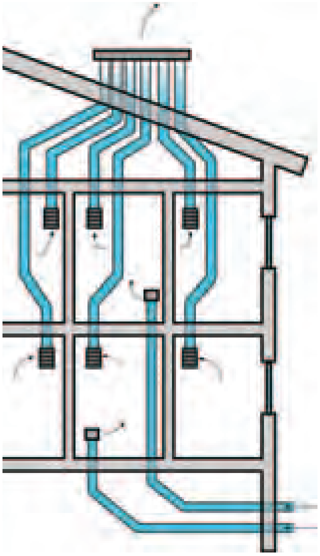
- Natural ventilation
- Mechanical ventilation systems

Comfort ventilation systems in buildings are normally designed so that the spread of fire and fire gases to adjacent fire compartments is limited. This is normally achieved by insulating the ventilation ducts with incombustible insulation, or by providing the ducts with dampers that automatically close if a fire occurs. The ventilation system should in principle have similar protection from the spread of fire and fire gases as the rest of the building.

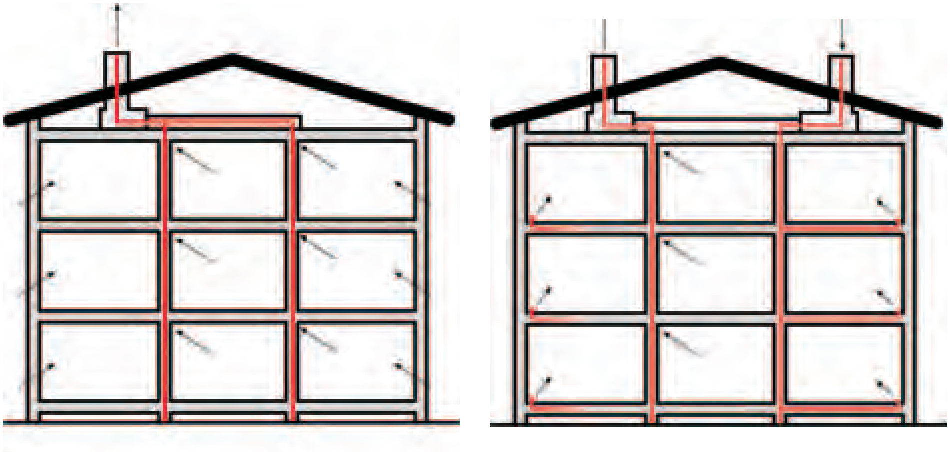
Natural ventilation

Natural ventilation functions by means of the temperature differences that naturally occur in buildings, in the shafts in the buildings, and in the ducts. This type of system is normally an exhaust air system, i.e. the ducts are normally only intended for exhaust air. Wood stoves and tiled stoves were often used as exhaust air ducts in older houses. The supply air was taken in through natural gaps in the building. From the 1920s, separate ducts were often installed for both supply air and exhaust air. Natural ventilation can now almost only be found in summer houses.

Natural ventilation does not normally contribute to the spread of fire gases between fire compartments, since the ventilation takes place in separate ducts.



Natural ventilation is common in buildings from the 1920s.



In buildings erected during the 1960s it is common to find outlets, or inlets and outlets.

Mechanical ventilation systems

Mechanical ventilation systems can designed as:

- Supply air systems. Fans supply air through the ventilation ducts. The exhaust air is pressed out through gaps in the room or to adjoining rooms. The system creates positive pressure in the fire compartments.
- Exhaust air systems. Fans suck out air through the ventilation ducts. The supply air is drawn in through gaps in the room or from adjoining rooms. The system creates negative pressure in the fire compartments.
- Closed supply and exhaust air systems. Fans connected to the rooms, supply them with both supply air and exhaust air through ventilation ducts.
- Open supply and exhaust air systems. Fans connected to the rooms, supply them with both supply air and exhaust air through ducts. The exhaust air is also allowed to flow through gaps both to the surroundings and to adjoining rooms.

Normally the spread of fire gases to adjoining rooms in the building would be on a small scale, as long as the mechanical ventilation systems are in operation. If all, or parts of the mechanical ventilation systems stop working, this can strongly contribute to the spread of fire gases in buildings. This can be a problem, especially in the case of open and closed supply and exhaust air systems, since the different fire compartments are often linked through ventilation ducts. As a rule the spread of fire gases (and also smells from cooking and bad/old air etc.) is prevented by the pressure difference over the ventilation device (the hole in the wall). If the ventilation system stops working this pressure difference will be lost, and fire gases can easily be spread via the ventilation ducts between the different fire compartments/rooms. With functioning mechanical ventilation systems there is little risk of spreading fire gases through the ventilation system. If the ventilation system stops working this can contribute to the spread of fire gases between fire compartments in buildings.

A modern ventilation system can be an integrated part of the protection in the building, in which case the design and function of the system would then be based on a specific dimensioned fire pressure. By ensuring that the ventilation system works even during a fire, and as long as this dimensioned fire pressure is not exceeded, the system can often manage to prevent the spread of fire and fire gases for quite a long time. In such cases it can be important to make sure that the ventilation system maintains its function by, for example, the fire and rescue services putting in additional measures to protect the system.

Air/smoke that is heated up expands and takes up more space, which causes the pressure to increase.

Thermal expansion

When there is a fire in a completely closed room there will be a build up of pressure as a result of the heating and expansion of the air. For small or moderate differences in temperature this pressure will be small, i.e. when it is not burning, but in the case of fires where the temperature can reach many hundred degrees this pressure difference can have a substantial effect, especially if the fire develops quickly. If the size of the fire remains constant the pressure will increa-

Fires in rooms with only minor leakage openings (gaps) normally only produce pressures in the magnitude of several tens Pascal as a result of inhibited thermal expansion.

Adiabatic
Work or a process that takes place adiabatically, takes place without any exchange of heat to the surroundings.

Calculation of thermal expansion

Starting from the energy balance equation for a control volume and assuming that the leakage openings are at floor level, the heat losses to the walls are negligible, in similarity with the change in the adiabatic work effected during the increase in pressure, and that the development of the intensity of the fire $\dot{Q}$ is constant, then the pressure increase in the room can be calculated by means of the formula:

$$\Delta p = \frac{(\dot{Q}/c_p\, T_e\, A_e)^2}{2\rho_e}$$

where c_p is the specific thermal capacity at constant pressure, T_e is the temperature in the outflowing air, A_e is the leakage area, and ρ_e is the density of the outflowing air.

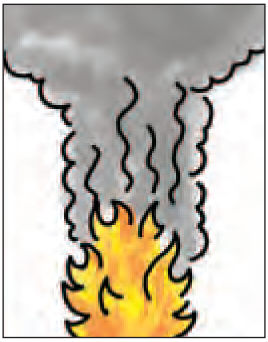
Assume that the development of the intensity of the fire Q from a burning paper basket in a standard office is 100 kw. The volume of the room V is 60 m^3. The room is fully sealed with the exception of a gap that is 2 cm high and 1 metre wide, i.e. 200 cm^2. The maximum increase in pressure will then be:

$$\Delta p = \frac{(100/1 \times 293 \times 0 \times 0.02)^2}{2 \times 1.3} = 110 \text{ Pa}$$

Most panes of glass can withstand 110 N without problem. Since a fire in a room normally grows in size, the pressure will be subsequently equalised as a result of gaps and leakage. A positive pressure as high as 110 Pa seldom occurs.

se linearly, i.e. the pressure increases constantly in time.

Normally there is a certain leakage of air in the fire room, for example in the form of comfort ventilation or gaps at windows and doors. Since a fire in a room normally grows in size, the pressure will be subsequently equalised as a result of gaps and leakage. The increase in pressure will therefore as a rule only be in the magnitude of ten or several tens Pascal.



Hot air, in similarity with hot smoke, is lighter than cold air and therefore rises upwards.

Thermal buoyancy force

Hot gases are produced when a building is burning. These hot gases have a lower density than the unaffected ambient

Fresh air flows in through the lower part of the window. Hot gases flows out through the upper part of the window.

air and therefore rises upwards, which in this connection we refer to as thermal buoyancy force. In the ideal case we would have a room with an upper layer of hot gases and a lower layer mainly consisting of unaffected air. If we look at the entire building, the hot gases will flow upwards in the building, for example in a stairway.

As long as the fire gases has a higher temperature than the ambient air, and therefore a lower density, it will rise upwards. The buoyancy force, in combination with the thermal expansion, causes the fire gases to be forced out through openings situated high up. This can often be clearly seen in the openings to the fire room, where fresh air flows in through the lower part of openings and hot gases flows out through the upper part.

Calculation of thermal buoyance force, see next page.

The fire gases cools down as it rises upwards. This means that in high buildings the gases might not reach the roof, but will stop and may in fact subside. In the same way the fire gases can subside to the floor when it flows into a long corridor, or a tunnel, and is cooled by the ceiling and walls.

Calculation of thermal buoyancy force

The pressure difference as a result of thermal buoyancy force can be calculated as per:

$$\Delta p = (\rho_a - \rho_g)\, gh$$

or simplified as:

$$\Delta p = 353 \left[\frac{1}{T_a} - \frac{1}{T_g} \right] gh$$

The temperature is given here in Kelvin. Assume there is a room with an approx. 1 m thick layer of smoke. The smoke has an average temperature of 400°C. The thermal pressure difference over this layer (from the bottom to the top of the smoke) will then be:

$$\Delta p = 353 \left[\frac{1}{293} - \frac{1}{673} \right] 9.81 \times 1 = 6.7 \text{ Pa}$$

Pressure conditions during fires in buildings and during fire ventilation

Fire ventilation means that the pressure conditions in and around a building are changed or utilised in such a way that fire gases is made to flow out from the building. The gases flows from high pressure to low pressure. It is therefore the size of the pressure difference that determines whether the fire gases will flow at all, and how much and how quickly it will flow. Large pressure differences produce large flows, or cause the gases to flow at high speed.

The pressure conditions in and around buildings are often extremely complex. The acting pressures, as described above, are primarily produced as a result of:

Normal pressure differences

a. differences in temperature between outdoor and indoor air
b. the effect of the wind
c. comfort ventilation (mechanical ventilation and natural ventilation)

Pressure differences created by the fire
a. inhibited thermal expansion
b. thermal buoyancy force

All these pressures are of the same magnitude, which means that even very small changes in one pressure can influence the flow of fire gases significantly.

During different types of fires in different types of buildings, with different conditions, one or more of the types of pressure differences described above can dominate to a greater or lesser degree. A commanding officer about to make a decision about fire ventilation, must therefore picture for himself which of the pressure differences are the most dominant.

In very high buildings with shafts the differences in temperature between the outside and inside air will cause large pressure differences. These pressure differences can be considerable, especially during cold or very warm weather.

The wind can have a very large effect on the spread of fire gases, both inside buildings and to other buildings, especially in certain geographic locations or at high elevations (high buildings).

Comfort ventilation can in certain types of buildings, above all those with open or closed supply and exhaust air systems, cause problems with the spread of fire gases, especially if the ventilation system stops working.

Fires in buildings create pressure differences as a result of inhibited thermal expansion, i.e. the hot gases expands, and also as a result of the thermal buoyancy force, i.e. hot air rises upwards. In the case of fires where the intensity develops rapidly, or fires that spread quickly, these pressure differences taken together can be considerable.

If the boundary of a fire compartment is defective, or if the structure is weakened as a result for example of the impact of the fire, the pressure differences that arise can further weaken the boundary of the fire compartment or the structure, especially during very intense or rapid fire scenarios or at high temperatures.

The different pressure differences acting in and around a burning building are approximately of the same magnitude. This means that the spread of fire gases in and around buildings is extremely complex and very difficult to assess.

Which pressure dominates and causes the most effect will vary from case to case. If there is a strong wind, it can be the wind that causes the largest pressure difference and thereby causes the greatest effect. If the fire is very intense and the temperature in the fire room and even other adjoining rooms is very high, the pressure differences resulting from the thermal buoyancy force or the thermal expansion can be the most dominant. The dominating pressure difference can also vary during the course of the fire. In the initial stage of a fire, or during small fires, it can be the comfort ventilation that has the greatest effect on the spread of fire gases, especially the spread of fire gases that takes place in the fire compartment as a result of the movement of air produced by the comfort ventilation. At a later stage in the fire scenario, especially if the temperature is high or if there is a fully developed fire, the comfort ventilation can also contribute to the spread of fire gases to other fire compartments.

The decision as to what the rescue services should do in these different cases is extremely complex, and an assessment of the tactical problems must be made in each individual situation. When using fire ventilation, however, an attempt should be made to get the different pressure differences to coordinate in order to achieve the desired result.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CHAPTER 5

Working with fire ventilation

The object of fire ventilation is to attempt to change the pressure and temperature conditions prevailing in a burning building with a view to releasing fire gases. Pressure and temperature conditions can be changed in different ways, however, depending on how the fire ventilation is implemented. It can basically be implemented in two different ways, horizontally or vertically, but these two methods can also be combined with mechanical fire ventilation. In certain cases fog nozzle ventilation can be used.

The size of openings

In general it is not possible to specify any absolute values as to how large openings should be. It is, however, possible to specify certain guidelines for how different sizes of openings affect a fire scenario and the flow of fire gases. For fire ventilation to achieve the desired effect it is important for it to be implemented at the right time and in the right place in relation to the location, size and development of the fire. Above all both inlets and outlets must be of a certain minimum size. The temperature in the fire room is a determining factor for the size of the outlets, which in turn is governed by the size and development of the fire. The size of the outlets also depends on what is to be achieved by the fire ventilation. There is, however, a certain correlation between the size of the inlets and the size of the outlets. To allow a certain volume of fire gases to flow out, a (minimum) corresponding volume of air must be able to flow in.

For practical reasons it can sometimes be difficult to achieve openings that are sufficiently large. Roof trusses, supporting or separating walls, and the size of windows and doors, can be limiting factors. There are, however, certain factors that directly influence how large openings should be. For example a high temperature in the fire room means that large openings should be made, since a high temperature can imply a large fire that produces a lot of hot gases.

On the other hand it is not a good idea to make the openings too large. It can often be better to make several small openings instead of one large opening. Small openings, however, have larger flow losses (greater resistance to the outflowing fire gases) in relation to the volume of gases that is to be vented out. The number and size of the openings also depends on what the purpose of the measure is. If in addition to fire ventilation, the purpose is also to physically separate structures it would obviously be better with a large opening, for example right across a roof.

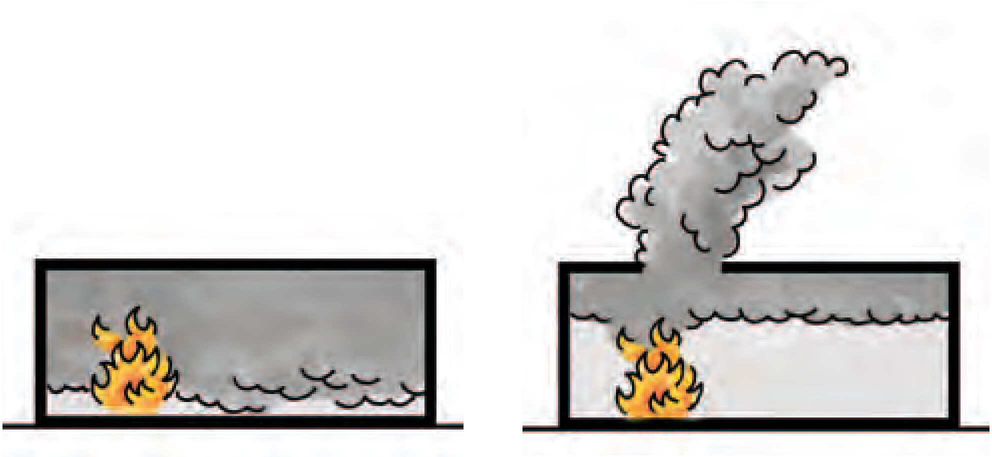
It should also be borne in mind that it actually takes quite a long time to make the openings. A large hole, however, would not necessarily take much more time to make than a small hole. A lot of the time is spent of course on the actual preparations, such as providing safety precautions for the crew and the tools.

Outlets

Outlets are the openings where fire gases flows out from the building. They can consist of existing openings (windows and doors) or openings that are made by means of various tools. In general outlets should be made as high as possible, so that the thermal buoyancy force of the hot gases can be fully utilised. Help can often also be obtained from the prevailing wind conditions. Outlets should be made where it is hottest, regardless of whether the ventilation is for rooms exposed to fire or adjacent rooms. The problem is that this is most often the place where the structure has been most weakened.

Watt

Rate of heat release is measured in watts [W], which is the same as the specified joule [J] energy per second [s], J/s. The development of the intensity of a fire is often specified in kilowatts (one thousand watts) or megawatts (one million watts).



The requisite size of outlets is determined above all by the temperature of the fire gases. If the fire is a large fire, or has been in progress for a long time, larger outlets will be needed to achieve the corresponding venting of the hot gases. The higher it is wished to raise the layer of fire gases, the larger the opening that will be needed. A common criteria for ventilation measures is that enough fire gases can be vented out to improve visibility for the fire fighters. In practical situations one would normally want to vent out as much of the fire gases as possible.

Relatively modest ventilation openings are often enough to achieve an essential improvement of the environment in a fire room. In rooms with up to several hundred square metres of floor space with fires of several megawatts up to isolated cases of ten megawatts, it is often enough with openings of a few square metres to achieve a noticeable effect of the fire ventilation.

The following guidelines can be applied:

- The higher it is wished to raise the layer of fire gases, i.e. the greater the effect of the fire ventilation that is required, the larger the outlet should be. (Note the maximum size of outlets, given below.)
- The higher the gas temperature in the fire room, the larger the outlet needed to achieve the intended effect. The temperature of the gases depends among other things on the development of the intensity, i.e. high temperature means high intensity, in relation to the volume of the room, which also implies that a lot of fire gases is produced.

When an opening has been made it is often possible to see a clear lifting of the layer of fire gases, i.e. a relatively clear zone is created close to the floor, and this considerably improves working conditions for the fire fighting crew.

Examples of characteristic intensities of fires

Paper-basket	0.05–0.3 MW
Sofa	1–2 MW
Kiosk	5 MW
Office room	1–2.5 MW
Engineering workshop	2.5–5 MW
Bed	1–2 MW
Motor car	2–4 MW
Lorry	15–60 MW

Calculation of the size of outlets

The maximum outlet is determined among other things by the Froude number, which gives the square root from the relationship between either the inertial force and gravitational force, or the kinetic energy and potential energy. From critical values of the Froude number it is possible to derive a simple rule of thumb for the maximum opening area A_v (separate openings):

$$A_v < 2 \times d^2$$

where d is the thickness of the smoke layer.

This means, for example, that if in an industrial building completely filled with fire gases and with a ceiling height of 3 m, it is wished to raise the layer of fire gases to half the ceiling height, then each separate opening (or group of openings in direct connection with each other) should not be made larger than approximately:

$$A_{v,\,max} \approx 2 \times \left(\frac{3}{2}\right)^2 = 4{,}5\ m^2$$

In total, however, a larger opening area than this can be required. This can then be achieved by creating several openings with the maximum opening area.

Large outlets can cause fresh air to flow in and cool the smoke. This reduces the effect of the fire ventilation.

The single most important parameter that influences the size of outlets is the temperature. The temperature is directly related to the intensity of the fire, and also to the pressure difference over the layer of fire gases. A high temperature corresponds to a high intensity and means that more fire gases are produced, but also that there is larger thermal buoyancy force. The size of the opening or openings needed for fire ventilation increases in relation to the development of the intensity of the fire.

To achieve the best effect with fire ventilation it is important not to make the openings too large in relation to the fire and the thickness of the layer of fire gases. If the opening is too large fresh air from the inlets can flow directly out with the fire gases, which naturally reduces the effect of the opening. This is, however, usually only a minor problem in the context of fire and rescue operations.

Outlets should be placed where the temperature is highest, i.e. as high as possible.

The size and development of the fire (temperature of the smoke) and the size of the room are critical for the determination of the size of outlets, but 4–8 m^2 can serve as a guideline, with smaller sizes for small buildings and larger sizes for large or very large industrial buildings.

Creating openings in structures takes a long time. It can often be better to make a number of small outlets instead of a few large openings.

Inlets

Fire ventilation is often associated with making openings to vent out fire gases. Nevertheless it is equally important, if the gases are to be vented out at all, that there are inlets where air can flow in and replace the gases that flows out.

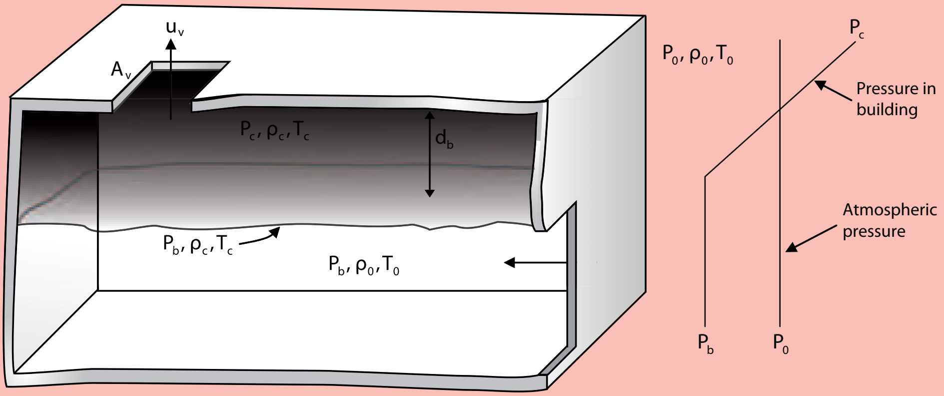
It can often be more difficult to make inlets than outlets. In general inlets should be below the layer of fire gases, i.e. level with or below the fire, since hot air rises upwards and fresh air should then be filled from underneath. For practical reasons the supply air often needs to be arranged at a good distance both from the fire and the outlets. In certain cases outlets in the form of vents in the roof can be used as inlets. This assumes, however, that the vents are placed on the roof to adjacent rooms that are not directly exposed to the fire or fire gases, and that there are internal openings between these rooms and the rooms exposed to the fire.

Since fire gases consists for the most part of fresh air that has been supplied to the fire, heated up and expanded, the size of the inlets in relation to the outlets will be an approximate ratio of 1:1 to 2:1, i.e. inlets should be at least as large as and up to twice as large as outlets. An attempt to make even larger inlets would normally have no significance. Since room divides, openings between rooms and the positioning of interior furnishings, limit the flow of the air, it is almost always preferable to strive towards having somewhat larger inlets than outlets, especially if there is a considerable distance between the inlets and outlets. Inlets larger than this lead to only a small or negligible increase in the intended effect.

Inlets should be positioned as low as possible. The total area of inlets should be at least equal to and preferably up to twice the size of the total area of the outlets.

The relationship between the size of inlets and outlets during thermal ventilation

Consider a room with an upper layer of hot gases with a thickness of d_b, pressure P_c, density ρ_c and temperature T_c. In the lower part of the room the pressure is P_b, the density is ρ_0 (same as the ambient air) and the temperature is T0 (same as the ambient air). The speed of the outflowing smoke through the outlet in the roof, with an area of A_v, is u_v. The speed of the inflowing air through the inlet, with an area of A_i, is $u_{i.}$



The pressure drop over the outlet is:

$$P_c - P_0$$

The pressure drop over the inlet is:

$$P_0 - P_b$$

Bernoulli's equation gives:

$$P_c - P_0 = \frac{\rho_c \times u_v^2}{2}$$

Equation 1

$$P_0 - P_b = \frac{\rho_0 \times u_i^2}{2}$$

Equation 2

The static pressure resulting from the temperature of the smoke is given by:

$$P_c - P_b = (\rho_0 - \rho_c) \times d_b \times g$$

Equation 3

The relationship between the temperature and density is given by:

$$\rho_0 \times T_0 = \rho_c \times T_c \Rightarrow \frac{T_o}{2} = \frac{\rho_c}{\rho_0}$$

Equation 4

The temperature difference is:

$$\theta_c = T_c - T_0$$

Equation 5

The equations 1—2 give:

$$P_c - P_b = P_0 + \frac{\rho_c \times u_v^2}{2} - P_0 + \frac{\rho_0 \times u_i^2}{2} = \frac{\rho_c \times u_v^2}{2} + \frac{\rho_0 \times u_i^2}{2}$$

Together with equation 3 this gives:

$$\frac{\rho_c \times u_v^2}{2} + \frac{\rho_0 \times u_i^2}{2} = (\rho_0 - \rho_c) \times d_b \times g$$

Division with the density ρ_0 gives:

$$\frac{\rho_c \times u_v^2}{\rho_0 \times 2} + \frac{u_i^2}{2} = d_b \times g - \frac{\rho_c}{\rho_0} \times d_b \times g$$

which together with the equations 4 and 5 gives:

$$\frac{T_0 \times u_v^2}{T_c \times 2} + \frac{u_i^2}{2} = \frac{d_b \times \theta_c}{T_c} \times g$$

Equation 6

The mass flow through the inlet can be described with:

$$M_i = C_i \times A_i \times \rho_0 \times u_i$$

Equation 7

The corresponding flow for the outlet means, together with equation 4 that:

$$M_v = C_v \times A_v \times \rho_c \times u_v = C_v \times A_v \times \rho_0 \times u_v \times \frac{T_0}{T_c}$$

Equation 8

If A_i and A_v are equal and uniform:

$$C_i = C_v$$

Equation 9

We assume that all the inflow takes place through A_i and all the outflow through A_v. We also disregard the mass flow from the fuel, i.e.

$$M_i = M_v$$

Equation 10

The equations 6—10 then give:

$$M_v = \frac{C_v \times A_v \times \rho_0 \times (2 \times g \times d_b \times \theta_c \times T_0)^{1/2}}{T_c^{1/2} \times \left[T_c + A_v^2 \times \frac{T_0}{A_i^2}\right]^{1/2}}$$

Equation 11

If A_i goes toward infinity, i.e. of there is an unlimited supply of supply air, the equation (11) becomes:

$$M_v = \frac{C_v \times A_v \times \rho_0 \times (2 \times g \times d_b \times \theta_c \times T_0)^2}{T_0 + \theta_c}$$

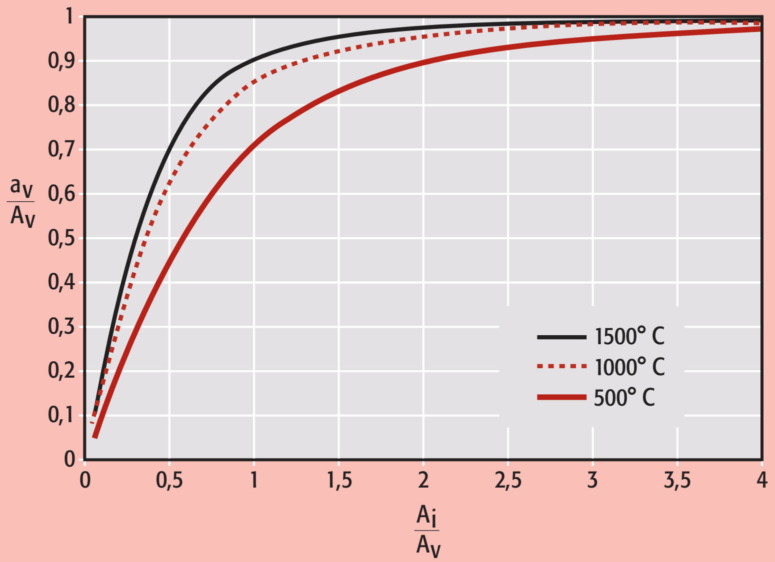
Equation 12

The equations 11 and 12 become completely identical if A_v is replaced with a corrected ventilation area, a_v, defined by:

$$\frac{1}{a_v^2} = \frac{1}{A_v^2} + \left[\frac{1}{A_i^2}\right] \times \frac{T_0}{T_c}$$

Equation 13

Let us draw in a diagram the relationship between the inlet area, A_i, and the outlet, A_v, in relation to the relationship between a_v and A_v, which will be a way of measuring the efficiency of the outlet. We now see that the efficiency increases the larger the inlet is. From the diagram it is possible to draw the conclusion that the inlet should be at least the same size as the outlet, and preferably twice as large, when the efficiency becomes approx. 90%. Note also that this relationship also depends on the temperature, even if this does not change the conclusion.



Horizontal fire ventilation of rooms exposed to fire

In many buildings it is not possible to create openings above the fire. This can be the case, for example, where there is a fire in an industrial building with a lightweight concrete roof or in an apartment in an apartment block, where ventilation through existing windows or doors is the only possibility. So-called horizontal ventilation is based on outlets at the same level as the fire. This normally creates no upward flow of the fire gases in the building, and the fire gases flows out horizontally through the outlets (normally windows or doors).

Horizontal ventilation is normally implemented by using the building's permanent openings (windows, doors or vents) to the greatest possible extent to vent out the fire gases. Openings occupying a high position on the leeward side should be used as outlets. Openings occupying a low position on the wind side should be used as inlets. In this way it is possible to utilise the thermal buoyancy force of the hot gases to the greatest possible extent, and also the pressure of the wind, to vent out the gases. If this does not work it will be necessary to consider which produces the

Openings and ventilation can be implemented by using windows and doors, so-called horizontal fire ventilation. The fire gases flows horizontally from the fire/fire room and out through the windows or doors.

Horizontal fire ventilation means that the outlets are at the same level as the fire. This reduces the effect of the fire gases' thermal buoyancy force, but is often the only way of venting, for example in the case of apartment fires.

largest pressure difference, the temperature of the hot gases or the wind.

The effect of horizontal fire ventilation can be improved with the help of fans. This will be described in more detail further on.

Vertical fire ventilation of rooms exposed to fire

Vertical fire ventilation means that the outlets are above the fire, often as high up as possible in the building. The smoke then flows out vertically, i.e. upwards, from the fire or from the fire room and out through the outlets. The inlets on the other hand should, as described above, be on a level with or below the fire.

High outlets are normally implemented by making an opening in the roof structure, or also by using existing hatches (windows/apertures or vents/shutters).

Openings and ventilation can sometimes be implemented through openings (high up) or hatches in the roof, so-called vertical fire ventilation. The fire gases flows vertically from the fire/fire room tand up through openings in the roof.

Basement fires can often cause a problem, where outlets can be arranged above the fire, but where inlets also have to be arranged above the fire. In this situation it is especially important to make use of the wind or to use fans. In certain cases it may be necessary to use the same opening for both the supply and exhaust air.

The effect of vertical fire ventilation can be improved with the help of fans. This will be described in more detail further on.

Vertical fire ventilation means that the outlets/inlets are above the fire, often as high up as possible in the building. In this way it is possible to utilise the thermal buoyancy force of the hot gases.

When a room or a fire cell is considered to be lost it can often be better to focus on protecting adjacent rooms, for example by creating openings and venting the adjacent room.

Fire ventilation of adjacent rooms

When a fire in one room is fully developed it can be more appropriate to implement fire ventilation in adjoining rooms than to vent the room where the fire is burning. The purpose of this is to prevent the spread of the fire and hot gases to non exposed rooms (e.g. adjoining fire cells).

Fire ventilation of adjacent rooms is normally implemented as the pressurising of these rooms (see below) or by creating openings in the roof. The openings can then be made as a trench, i.e. the physical separation of the roof between the part that is burning and the part of the building that is not yet damaged. These openings can, however, be made both horizontally and vertically, and can also be combined with mechanical ventilation.

Mechanical fire ventilation

Mechanical ventilation can be implemented by using fans. Negative pressure ventilation means that fire gases is sucked out from the fire room or from adjacent rooms. Positive pressure ventilation (PPV) means that air is pressed into a room exposed to fire with the help of fans, in combination with a swift fire attack. It is also possible to pressurise adjacent rooms. There is often very little to distinguish the pressurising of adjacent rooms from positive pressure ventilation: for example, when implementing positive pressure ventilation in the case of an apartment fire it is also possible to achieve the effect of pressurising the stairwell. It is also possible to implement various types of positive pressure ventilation. Mechanical ventilation must be combined with creating openings, so as to achieve horizontal or vertical ventilation (i.e. so that both inlets and outlets are achieved).

Note that mechanical fire ventilation can have a significant effect on the fire scenario. For this reason extreme caution should be observed when using fans, regardless of how the ventilation is implemented.

Negative pressure ventilation

Negative pressure ventilation is based on creating a negative pressure in an opening to the fire room, or to the room exposed to fire, by means of a fan. Alternatively the negative pressure can be created by means of a fan in the middle of the room or in the building. This fan is then interconnected with the surroundings, for example by using a large diameter tube. There are also instances where the fan is placed outside the building, with a large diameter suction tube that is led into the building.

Negative pressure ventilation can be used as a tactical measure during a fire and rescue operation, but is preferably used during mopping up and salvage and overhaul. The method requires several preparations. If the fan is placed for example in an opening, the rest of the opening must be covered. It may also be necessary to use a large diameter tube to remove hot gases.

Situations where negative pressure ventilation can be suitable include fires in basements or other fire rooms that are not in direct connection with the outside, and where fire gases must be transported through rooms that have not yet been affected, for example via a stairwell. Negative pressure ventilation can also be applicable when the same opening has to be used as both inlet and outlet. During mopping up/salvage and overhaul the technique can be used to improve the working environment for fire fighters, who for example have the task of demolishing the roof/walls to access hot-spots.

During negative pressure ventilation the inlets can be arranged separately. If a large diameter tube is used, it is possible to use the same opening as the one where the large diameter tube is placed. If the same opening is used for both supply and exhaust air (through large diameter tube) the large diameter tube should be led a sufficient distance into the room exposed to fire so that fresh air does not flow directly from the inlet to the large diameter tube and directly out into the open.

The self-supporting large diameter tube on the negative pressure side is placed as far into the room and as high up as possible to capture hot smoke under the ceiling. It may be necessary to place an extra fan in the room to stir the smoke to prevent stationary pockets forming in corners, etc. There are different techniques in use to place a fan or self-supporting large diameter tube under the ceiling, for example expander rods in doorways that the fan can be hung from. Specially manufactured adjustable frames are also used on occasions.

The large diameter tube on the suction side must be self-supporting, while the large diameter tube on the pressure side can be flexible. Note that in both cases the large diameter tubes must be capable of withstanding high temperatures. Flexible large diameter tubes of polythene or the equivalent, so-called disposable large diameter tubes, withstand a maximum of 100°C, and are therefore not suitable to be used for outlets when venting rooms with hot gases.

Negative pressure ventilation sets severe demands on the fan, which should be able to withstand high temperatures. If the fan is run by an internal combustion engine the power output can be reduced as a result of the influence of the fire gases.

Fire ventilation can be implemented by allowing fans to suck out fire gases from a building, so called negative pressure ventilation.

The volume of fire gases that can be vented out by means of negative pressure ventilation is limited, above all by the capacity of the fan, but also by the flow resistance in the large diameter tube. The resistance increases and the flow diminishes the longer the length of the large diameter tube and the smaller the diameter. Electric fans have traditionally been used for negative pressure ventilation. These fans have a relatively small capacity, approximately 2,000–

Negative pressure ventilation is normally used during mopping up and salvage and overhaul.

The fan is placed high up in an opening, or is combined with a large diameter tube.

The large diameter tube on the fan's suction side must be self-supporting, while the large diameter tube on the fan's pressure side can be of the simple polythene type (soft plastic).

Note that hot gases can damage both the large diameter tube and fan.

Negative pressure ventilation is suitable for basement fires, when the fire gases must be transported through rooms not yet affected, or when the same opening must be used for both inlet and outlet.

The method can also be used to vent rooms where hazardous, explosive or toxic gases have leaked out. Pay attention to the risk of explosion!

Negative pressure ventilation can simplify filling a room with high expansion foam.

8,000 m^3/h (approx. 0.5–2 m^3/s). As a rule the size of the fan increases in relation to the capacity.

This method can be used for both small and large fires, even if it is of most advantage in the case of small fires. The larger the fan (higher capacity) used and the smaller the room, the more quickly the fire gases will be vented.

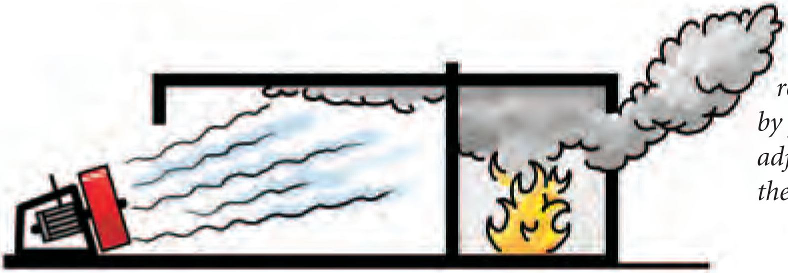
Negative pressure ventilation can also be used to vent areas where hazardous, explosive or toxic gases have leaked out. If the outlet can be limited to a large diameter tube from the affected area this can prevent the further spread of gases in the building, in that the supply air only comes through the natural leakage areas in the building. It is extremely important that the fan is explosion-proof, especially when working with flammable or explosive gases. Static electricity can be created in the large diameter tube, which increases the risk of explosion. When venting toxic gases it is important to take into consideration where the gases are to be transported, and that the outlet of the large diameter tube is placed so as to prevent further damage occurring.

Experience has also shown that what might function extremely well during one operation, might not function at all the next time in similar situations. This could, for example, be because negative pressure ventilation is sensitive to how the fan is positioned, or to where the outlets and inlets are placed in relation to each other and the fire.

A special situation where negative pressure ventilation is used is during the use of high expansion foam in buildings. To dispel the air quickly from a room that is to be filled with foam, a suction fan is placed at the outlet. This has proved to be a very useful solution to more quickly fill a room with high expansion foam.

Pressurising of adjacent rooms

The pressurising of adjacent rooms involves using a fan to create a higher pressure in adjacent rooms, i.e. outside the fire room. The purpose of this is to prevent the spread of fire and fire gases to adjacent rooms. This can be an appropriate measure when the fire is a large one or is difficult to get at, when it is difficult to implement fire ventilation of the fire room, or if the fire is otherwise difficult to suppress. However, it is necessary for the walls or other separations to have a certain fire resistance, i.e. that the walls or separations can withstand flames, high temperature or fire gases for a certain period, without the fire or fire gases spreading through them.



When an area or a fire cell is considered to be lost it can often be better to focus on protecting adjacent rooms, for example by pressurising the adjacent room with the help of fans.

The pressurising of adjacent rooms can be achieved by making only one inlet, and by placing a fan in it. If the spread of fire gases to the pressurised room is not extensive, this measure is often sufficient. If hotter gases has already managed to spread to the adjacent room, the pressurising should be supplemented with an outlet.

One alternative is to connect a large diameter tube to the fan, which leads fresh air into the adjacent room. In such cases it is possible to use disposable polythene large diameter tubes, since there will only be a low temperature in the large diameter tube. This can be an appropriate measure if the room is deep inside the building, or if rooms have a special value (archives, computer rooms, museums etc.). It is then important that other openings, apart from the opening for the large diameter tube, are blocked so as to achieve the greatest possible positive pressure in the room.

Positive pressure ventilation (pressurising of rooms exposed to fire)

Positive pressure ventilation involves supplying a lot of air to the fire room, or the fire compartment where the fire is, by means of powerful fans. This measure is often combined with internal fire fighting.

The purpose of positive pressure ventilation is to quickly localise the fire and to remove the heat so that further spreading of the fire is dampened, and so that the fire fighters can quickly start saving lives and extinguish the fire. The working conditions for the fire fighters is considerably improved, since temperatures drop and visibility becomes much better. Evacuating persons also have a greater opportunity to escape the effect of toxic gases, while it is easier for the fire fighters to find trapped persons more quickly. Positive pressure ventilation often makes it possible to implement rapid internal fire fighting in a safe way.

The method is based on placing one or more fans close to openings to push out and vent fire gases through outlets. A normal strategy would be to:

Positive pressure ventilation is based on using a powerful fan to blow air into the building at the same time as an extinguishing/life saving operation is carried out.

1. Prepare for fire attack/saving of lives
2. Localise the fire room
3. Make outlets
4. Start the fan, and place the fan so that it blows in through the inlet
5. Enter the building and attack the fire

Fans suitable for positive pressure ventilation are usually either powered by an internal combustion engine, or by a water turbine. The capacity lies between 8,000–50,000 m^3/h ($2–14\ m^3/s$), depending among other things on the capacity of the engine/turbine, the diameter of the fan, and the shape of the fan blades. Larger diameters of fans produce larger flows, and turbine powered fans produce larger flows

Fans can during positive pressure ventilation (or during the pressurising of adjacent rooms) be placed side by side (in parallel) to achieve a larger volume flow of air, or to cover larger openings, for example doorways. The pressure and volume flow increase considerably.

than fans powered by an internal combustion engine. Nevertheless, the flow through the fire room depends on the geometry of the room, the size and positioning of the outlet, the position of the fan, and the amount and positioning of the interior furnishings.

To prevent fire gases penetrating out through an inlet it is important for the air flow to cover the whole, or as much as possible, of the inlet. For normal openings (apartment doors or doors to stairwells) the distance should be approximately 1–3 metres, depending on the type and size of the fan. It is relatively simple to find a suitable distance by trial and error, both during training exercises and fire and rescue operations. It can, however, be difficult to cover the opening without losing a lot of the air flow.

It is often of little importance, however, if fire gases is allowed to flow out, for example out into a stairwell. The fan can be placed in the middle of the opening so that as much as possible of the air flow will go into the fire area, on the assumption that it does not obstruct the work of the fire fighting crew.

During positive pressure ventilation it is possible to place fans in parallel, i.e. beside each other, to achieve a greater pressure and a greater volume flow, or to cover large inlets, for example a garage door.

Fans can also be placed in series, i.e. after each other.

This has, however, proved to only have a limited effect. Neither the pressure, nor the volume flow are significantly increased.

There can also be considerable air flow losses. Among other things, the air flow rotates and is deflected as a result of the turbulence from the fan. Some of the air flow will hit both the ground and the walls, which means that a good part of the air flow will not actually reach the opening.

Further losses occur on the way from the inlet to the outlet (inside the fire room) at every constriction, for example doorways, and because of furniture or other large objects. The movement of the fire fighting crew inside the building can also create losses, especially if they are in openings between rooms.

To achieve the best possible results from positive pressure ventilation the ratio between the inlet and outlet should be at least 1:2. This means that the outlet should be at least the same size as the inlet, and preferably up to about twice as large. During positive pressure ventilation it is therefore, as opposed to other ventilation measures, important not to have an overlarge inlet in relation to the outlet.

Fans are sometimes placed in series during positive pressure ventilation (or pressurisation of adjacent rooms). This has, however, a limited effect and does not noticeably increase the volume flow or pressure.

A large outlet produces a larger volume flow through the fire area, but at the same time lower pressure. This means that there is an increase in the sensitivity, for example sensitivity to the wind.

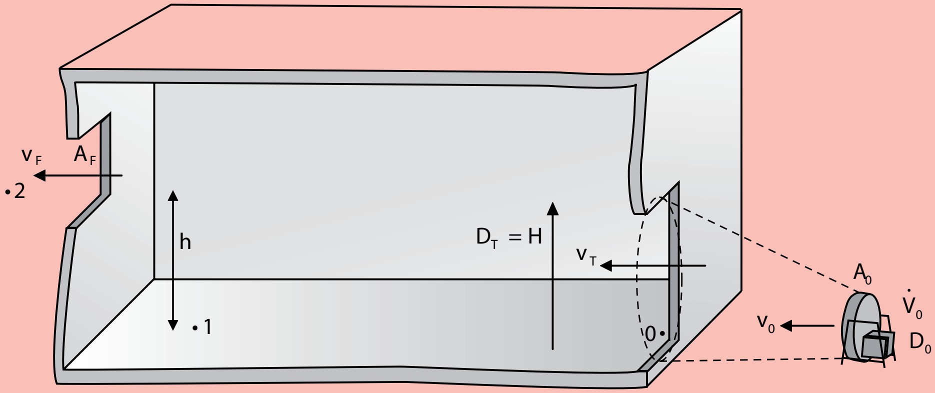
Positive pressure ventilation is a useful method, above all in apartments and small houses, where both the floor space and ceiling height are relatively limited (100–200 m^2 of floor space, 2–3 m ceiling height). The best results are achieved when the rooms lie after each other. It is then relatively easy to arrange the inlets and outlets in series with these types of room and corridors. In general it can be said that the method is useful during fires in small houses, apartments and apartment blocks where the fire gases can be transported through stairwells or corridors. The method can also function well in office premises and wards at health care centres etc.

The outlet should be made in the room that is burning most. However, it can often be difficult to determine where the fire is. It can be a problem, for example, if an apartment consists of two rooms and a kitchen joined together by only

To take into consideration during positive pressure ventilation:

- Create outlets.
- The ratio between the inlet and outlet should be 1:2, i.e. the outlets should be made twice as large as the inlets.
- Do not push the fire or fire gases to adjacent rooms or buildings.
- Do not push the fire or fire gases towards trapped persons, or fire fighting personnel.
- Do not implement positive pressure ventilation without having extinguishing water on hand.
- Coordinate positive pressure ventilation with other measures, for example, creating openings, attacking the fire and searching for trapped people. This will achieve the greatest advantages with this method.

The relationship between the size of inlets and outlets during positive pressure ventilation



Consider a room with an inlet with an area of A_T, an air speed of V_T and a height of H (=D_T, height/diameter of air cone), and an outlet with an area of A_F and a gas speed of v_F. The fan has an area of A_0 and a diameter of D_0, and the flow through the fan is V_0. We assume in other words that the air cone from the fan completely covers the inlet.

We disregard the actual fire. In those cases where positive pressure ventilation is primarily applicable this is a reasonable assumption, since in these cases the fan creates a much greater pressure than the fire. We also disregard the effect of the wind.

The law on the conservation of momentum gives:

$$V_T \times D_T = v_0 \times D_0 \text{ dvs. } v_T = \frac{v_0 \times D_0}{D_T}$$ **Equation 1**

The dynamic pressure exerted by the air cone (from the fan) to the inlet is given by:

$$P_{dyn} = \frac{\rho_0 \times V_T^2}{2}$$ **Equation 2**

The flow from the fan is given by:

$$\dot{V}_0 = v_0 \times A_0 = v_0 \times \frac{\pi \times D_0^2}{4}$$ **Equation 3**

The volume flow in the outlet is given by:

$$\dot{V}_F = C_d \times v_F \times A_F$$

Equation 4

where C_d is the outflow coefficient, and depends on what the opening looks like.

• •

Consider the points 0, 1 and 2 in the figure above, and apply Bernoulli's equation for these points. The height difference between the points 0/1 and the point 2 is h. This gives:

$$P_0 + P_{dyn} = P_1 + \frac{1}{2} \times \xi \times \rho_0 \times v_T^2 + \frac{1}{2} \times \rho_0 \times v_1^2$$

Equation a

$$P_1 + \frac{1}{2} \times \rho_0 \times v_1^2 = P_2 + \frac{1}{2} \times \xi \times \rho_0 \times v_F^2 + g \times \rho_0 \times h$$

Equation b

$$P_2 = P_0 - g \times \rho_0 \times h$$

Equation c

where ξ is the pressure loss coefficient in the inlets and outlets. The following is now applicable:

$$V_T = \frac{V_F \times A_F}{A_T} \qquad V_1 \approx 0, V_2 \approx 0$$

Insert the equations b and c in a, which gives:

• •

$$v_F = \sqrt{\frac{P_{dyn}}{\frac{1}{2} \times \xi \times \rho_0 \times \left[\left(\frac{A_F}{A_T}\right)^2 + 1\right]}}$$

Equation 5

With the help of the equations 1, 2 and 3 we obtain an expression for the dynamic pressure the fan exerts towards the inlet:

$$P_{dyn} = 8 \times \rho_0 \times \left(\frac{\dot{V}_0}{\pi \times D_0 \times H}\right)^2$$

Equation 6

Note. If the width of the opening is greater than H, the width is used.

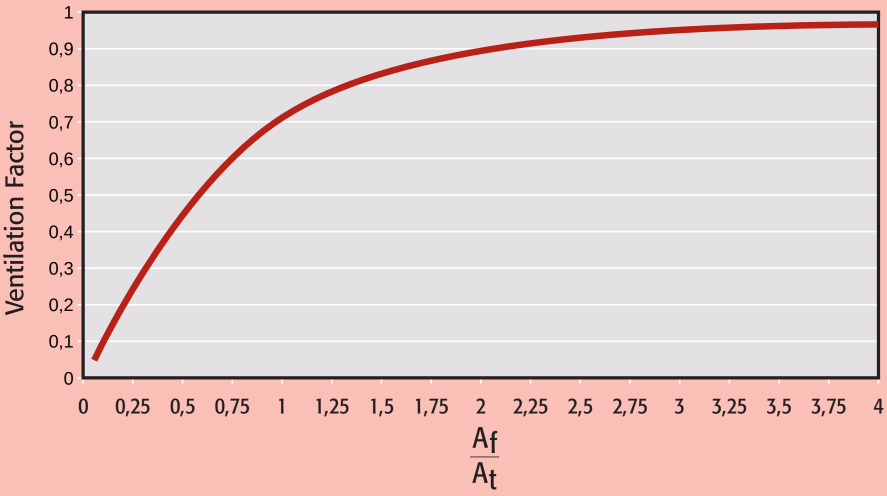
With the help of the equations 1—6 we also derive that:

$$\dot{V}_f = \frac{2.44}{\pi \times \sqrt{\xi}} \times \frac{H \times \dot{V}_0}{D_0} \times \left[\frac{\frac{A_F}{A_T}}{\sqrt{1 + \left(\frac{A_F}{A_T} \right)^2}} \right] \qquad \textbf{Equation 7}$$

We can call the expression in the large brackets the ventilation factor. We can draw in the relationship between the outlet, A_F, and the intlet, A_T, in relation to different values for the ventilation factor, from 0 to 1, see the diagram.

$$A_f >> A_t \Rightarrow \left[\frac{\frac{A_F}{A_T}}{\sqrt{1 + \left(\frac{A_F}{A_T} \right)^2}} \right] = \text{ventilation factor} \Rightarrow 1 \quad \textbf{Equation 8}$$

If the outlet is much larger than the inlet, the expression in brackets in equation 8 will go to 1. From this, and from the diagram, we can therefore draw the conclusion that the efficiency of positive pressure ventilation increases, the larger the outlet is. In the diagram we can see that the outlet should be at least the same size as the inlet, preferably twice as large, which gives a ventilation factor of approximately 90%.



a hall and no other internal connections. If an outlet is made in a room other than the room where the fire is this can considerably increase the risk of spreading the fire, increasing the intensity of the fire, and spreading the fire gases to other rooms, because there is a risk that the fan will push the fire and the fire gases to other rooms. This would completely, or partially, negate the positive results of positive pressure ventilation.

Positive pressure ventilation should be avoided for fires in large rooms. It can often work well, but there is a considerable risk that positive pressure ventilation will worsen the situation. Fire gases that was originally well stratified, hot gases in the upper part of the room and colder air at the bottom, can be brought into motion so that visibility becomes worse and the heat increases in the entire room. In such cases it is better to primarily pressurise adjacent rooms.

It should also be borne in mind that positive pressure ventilation supplies the fire with air. The intensity of the fire will increase, smouldering fires can flame up and quickly spread, the air flow will cause the fire to spread, and the heat between the fire and the outlet can be intense. Positive pressure ventilation should be used with care when:

- Backdraft conditions can occur, i.e. during powerful ventilation control and where the fire/pyrolysis has been in progress for a long period during such conditions.
- There is fire in concealed areas.
- There are structural fires, i.e. the fire has penetrated into a combustible structure and is mainly in progress in the structure.
- It is not possible to determine where the fire room is with certainty.
- There can be people between the fire and the outlet.

There are of course different ways in which positive pressure ventilation can be implemented.

A fog nozzle can be used for fire ventilation, by directing the flow out through, for example, a window.

Fog nozzle ventilation

Fog nozzle ventilation is a method that can be used in conjunction with extinguishing, for example during apartment fires. On completion of the extinguishing the fog nozzle is directed out through, for example, a window so that the flow of water draws the fire gases with it out through the opening. It is important that the flow of water is positioned in such a way that the cone formed by the suppression fog covers as much of the opening as possible. This method can be useful as an initial measure with a view to removing as much of the hot gases as possible before the mopping up work or demolition of the walls or roof is started. If there is an opportunity to use a fan, however, this is often to be preferred, since fog nozzle ventilation is ineffective when seen in relation to the achieved effect and the manpower resources required.

The method should be used with care, so as to avoid unnecessary water damage. The fog nozzle should therefore be opened outside the window, after which one backs into the room until the ventilation effect is achieved. Check what is outside the window, so that the water does not cause damage outside the building.

CHAPTER 6

Creating openings

Openings are an essential part of the work with fire ventilation. We will consider here the methods where openings are made manually by means of hand tools. Explosive cutting frames and water cutting are methods that require special training and special equipment, and will only be considered in general terms.

There are no general methods that can be applied for creating openings in roofs during fire ventilation in a fire and rescue operation (with the exception of explosive cutting frames and water cutting, which can be used in several different situations). On the other hand there are a large number of suitable tools that can be used, and certain guidelines can be given for creating openings in several common types of roof structures.

There are several factors that influence how successful ventilation can be implemented by creating openings in a roof. Examples of such factors are:

- the fire scenario and intensity of the fire
- room volumes and geometries
- the size and positioning of inlets
- the prevailing wind conditions
- access to mechanical ventilation
- the capacity of the fire fighting crew
- equipment to create openings
- the roof structure

The roof structure influences the tactics during the fire and rescue operation. It also influences the positioning and size of the openings, the time for and problems with the work of making the openings, including the safety precautions

Openings in tin plated roofs.

for the crew and the need for special tools. If the fire fighting crew has the right equipment and the roof structure permits an opening to be made quickly, the fire gases and fumes can in all probability be vented out enough to simplify the work of fire fighters.

On the following pages there is a description of the common tools used to create openings in the roof, and examples of openings made in different roof structures commonly found in Sweden. Unconventional measures, such as for example demolishing walls/roofs with the help of excavators or crane lorries are not considered. In certain cases these methods may very well provide suitable solutions to tactical problems, but they should be used with a certain degree of caution.

Always observe care when creating openings, especially when working on the roof!

Tools for creating openings in the roof

The tools shown are generally available at the fire and rescue services, and are used for the purpose of creating openings. They are divided up into electric motor powered tools, internal combustion engine tools, hand tools, and special equipment.

Electric motor powered tools

The electric motor powered tools are often smaller and lighter than the equivalent tools with internal combustion engines. The function of an electrically powered tool is not diminished by the fire gases and fumes when creating openings for fire ventilation. One of the disadvantages is that freedom of movement is limited by cables, and that access to electricity can be restricted in certain situations. Another disadvantage is that electrically powered tools often have a lower output than the equivalent tools with internal combustion engines.

Pay attention to the relevant safety regulations when using tools and machines.

Internal combustion engine powered tools

Tools powered by engines can be used regardless of external power sources and produce a comparatively large output. They are, however, relatively heavy and the engine power can be affected by the fire gases when creating openings. In the event of an intense development of fire gases the engine may at the worst stop. Engine powered tools should be used together with proper safety equipment. It is important to know how the tools should be used, among other things because of the relatively large output and their weight.

The cutting machine with twin-head rotating cutting discs cuts with two metal blades that are fitted beside each other and rotate in different directions. It can cut through stainless steel, cast iron and aluminium, wood, and certain plastics etc. On the other hand it cannot be used for glass,

Cutting machine with twin-head rotating cutting discs.


1


2


3


4


5

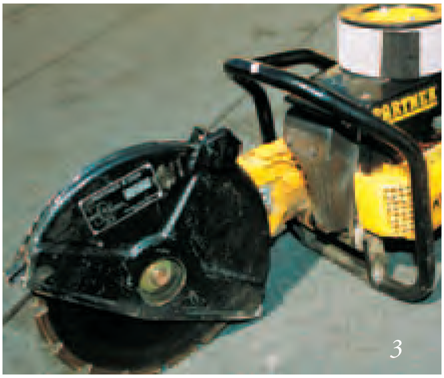

6

1. *Electric cutting machine.*
2. *Tiger saw.*
3. *Circular saw.*
4. *Electric chainsaw.*
5. *Electrical screwdriver.*
6. *Electrical screwdriver.*

stone, concrete or ceramics. The maximum cutting depth is 60–65 mm.

The electric cutting machine has a relatively minor practical application for creating openings in the roof, primarily because of its limited power. It can be fitted with different blades, and is mainly used for cutting metal parts in different roof structures, for example, metal rods and sheet metal hatches etc.

The tiger saw works with a reciprocating action. It can be used to saw in wood, plasterboard and metal. For the purpose of cutting sheet metal the cutting speed is slower than that of rotary tools, but the noise level is lower and it produces less sparks. The saw blade is approximately 15 cm long. The thicker the sheet metal, the lower the sawing speed.



1. Chainsaw
2. Power cutter.
3. Power cutter with alternative blade.

The circular saw is used to saw wood and plasterboard. It is effective and relatively easy to carry during an operation. It can be used for both boarding and supporting parts in wooden roof structures. The sawing depth varies from 50–70 mm, depending on the manufacture.

The electric chainsaw is handy for creating openings in wooden structures. Its function can be impaired by nails and metal jointing in the roof structure. When creating openings in wooden roofs covered with tarred roofing felt, the blade can stick because of the tar.

A special machine is used as a *screwdriver*, or a battery operated drilling machine is fitted with screwdriver bits or nut sleeve. The screwdriver is useful when it is necessary to remove sheet metal roofing that has been screwed on.

The chainsaw is handy for creating openings in wooden structures. Its function can be impaired by nails and metal jointing in the roof structure. When creating openings in wooden roofs covered with tarred roof roofing felt, the blade can stick because of the tar.

Iron bar, pincers, jimmy, crowbar.

Fireman's axe.

Cutting axe.

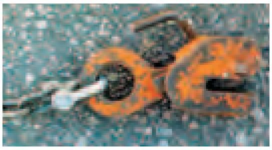
The power cutter is a heavy-duty tool that can be fitted with different blades, depending on what is to be cut. Users of power cutters, in similarity with other power tools, must be knowledgeable of its correct usage to ensure safety and efficiency. It should be run at full speed and allowed to eat its way through the material without being forced.

Different types of hand tools are iron bars, pincers, jemmies, crowbars, fireman's axes, and cutting axes.

Special tools

The jaws of *the sheet metal extractor* are tensioned over the sheet metal that is to be pulled down from the roof with the chain fitted in the tool, for example a lever. This works best on low roofs. If the sheet metal is securely fastened to the roof it can be difficult to pull off from a high roof with the lever, because the torque is excessive. To simplify removal on high roofs the fixing screws in the sheet metal can be unscrewed.

Explosive cutting frames are mainly used to create openings in roofs with folded metal sheeting on tongue and grooved boarding. The blasting frame consists of a rigid cellular plastic frame, which can be mounted together with other frames to enable the blasting of larger openings. The frame can be carried by one person and lifted through standard roof hatches (width 0.60 m). An explosive strip of a



Sheet metal extractor.

To right: Explosive cutting frame. Below: Firing takes place with a non-electrical ignition system consisting of a spring percussion igniter, ignition cable (so-called Nonel®) and detonator.

Water cutting.

plastic explosive is placed in the frame with a directional explosive effect, a copper material that cuts through the roof, foam plastic that holds the component parts together, and tape for adhesion to the underlayer.

Hydraulic powered eccentric cutting machines have the large advantage that the blade works eccentrically, i.e. the driving does not take place in the centre of the blade. The blade can therefore work in material with a depth greater than the radius of the blade (typical working depth approx. 25 cm). It can work in most materials. The disadvantage of the machine is that it requires hydraulic power by means of a separate hydraulic unit, and that it requires cooling.

Hydraulically powered eccentric cutting machine.

Water cutting involves using water at high pressure to cut an opening in a structure. The pressure can vary, depending on the equipment, from 200 to 300 bar. The water flow normally varies from 25 l/min. to 50 l/min. An abrasive additive (cutting agent) is often needed to cut through hard materials (roof materials etc.). A cooling and suppression effect is also achieved in conjunction with making an opening. Equipment for water cutting can normally cut through all the materials commonly found.

CHAPTER 7

Safety when working at high altitudes

Working at high altitudes, for example creating openings in conjunction with fire ventilation, always involves risks. To guarantee safety during such work it is necessary for the personnel to have the proper equipment, to be well trained, and aware of the risks associated with the work.

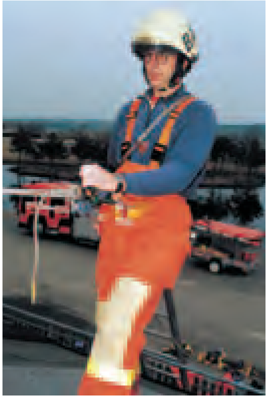
A full harness with peripheral equipment, or support equipment in the form of a fire belt or seat harness, is used when working at high altitudes. Only a full harness is approved as fall protection in accordance with the EN standard. Support equipment systems are, however, completely dominant in the Swedish fire and rescue services.

Example of full harness with accessories.

A fall protection system (full harness with accessories) is used to secure a person at an anchorage point, so that a possible fall would be braked in a safe way. Full harnesses are, for example, used when working on masts and in structural engineering.

A support equipment system (fire belt or seat harness with accessories) is used to prevent a fall and to provide support during the work. Support equipment systems are used, for example, when working on roofs, rappelling (lowering), and for work on poles.

In order to work safely in most situations at an altitude the following CE marked peripheral equipment is needed in addition to a seat harness/fire belt.



Example of seat harness (integrated in fire suit).

Rope	Kevlar rope 10–12 mm in diameter for work that can result in thermal stress on the rope. Core wrapped rope (static/dynamic) for other work.

Lowering device	Device with dead-mans grip.
Fall damper	To brake a possible fall.
Connecting line	Must not exceed 2 m in length.
Slings	Ready sown with sufficient length.
Spring safety hooks	Duralumin with safe locking, in certain cases screw locks.

Working at high altitudes

Safety measures must be taken when working in conditions where there is a risk of falling. When working on a roof, or from a ladder truck, in conjunction with fire ventilation it is most often advisable to be secured.

Securing during work from ladder or ladder trucks

Work is frequently carried out from both ladders and ladder trucks. The simplest way of securing oneself during such work at an altitude is to secure to the ladder or the ladder truck (top of the ladder or in the basket), in which case only a connecting line is used in addition to a belt or harness. The shortest possible line should be used. The connecting line can consist of synthetic rope, ribbon, wire or chain, and is an integrated part of both the conventional fire belt and the seat harness in the Rescue Suit 90 used by the Swedish fire and rescue services. The connecting line to the fire belt consists of a chain with attendant spring safety hook. The applications for both these items of equipment are rather limited for

Example of securing during work on ladder.

Top left: example of securing during work from ladder truck.

Top right: example of securing during work without ladder truck.

obvious reasons. It is mainly a question of securing yourself when working on a ladder, mast or the like.

To achieve a larger working area on the roof it is possible to use a ladder truck as an anchor point for a line, sling or a fall protection block.

Securing during work without ladder truck

Another common situation is working on roofs where it is not possible to secure to a ladder truck, or where for practical reasons it is necessary to leave the ladder or ladder truck in order to work more freely over a larger area. In this case an anchor point is needed to fasten the line, sling or fall protection block. This point must be able to withstand the resulting force if the person should fall. Such an anchor point could be a chimney, a roof ladder or a rail.

A safe escape route should also be created if possible, for example by placing and anchoring a ladder on the roof. As far as is possible this should be used as a work platform.

The actual creation of the opening should be carried out in such a way that there is always a safe escape route. The first cut in a roof should be made away from the work platform (ladder or ladder truck), so that the last cut can be made while standing on the work platform.

It can often be advisable to establish some form of standard operating procedure when working at high altitudes, the intention being to create a safe escape route and a safe work platform.

CHAPTER 8

Openings in different roof structures

There is no general method for creating openings that can be applied for all the different types of roofs that are encountered. More simple roof structures with a framework of wood or metal can often be dealt with relatively easily during a fire ventilation operation, while roof structures that contain thick concrete or steel must be considered to be impenetrable in such contexts. Nevertheless there are tools that can cut through concrete, for example the hydraulically powered eccentric cutting machine. Creating openings in such materials does take a long time, and is therefore only applicable in very special situations.

If fire ventilation is to be worth the effort it is essential that both the outlets and inlets are sufficiently large. The size of the fire and the premises are the determining factors, but for an outlet 4–8 m^2 can serve as a guideline.

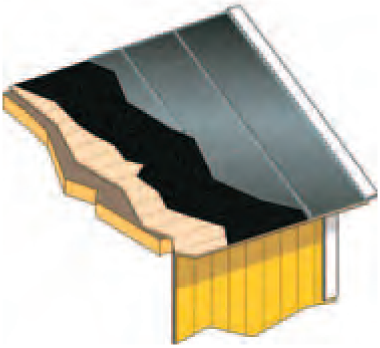
It takes time to create openings for fire ventilation, and regardless of which method is chosen and used the time factor must be taken into consideration. The fire develops and changes over time, and this means that the situation could be completely different when the openings are ready from what it was when the work was started or a decision was made.

The fire and rescue operation must be coordinated if fire ventilation is to be successful. The team participating in the operation should be experienced and trained in the use of the tools and the methods applicable for creating openings in different roof structures. At least two, or preferably three persons should be available for this purpose. The size of the fire, the type of roof structure, and the choice of tools/method will nevertheless determine how many persons are needed. The safety aspects must also be taken into consideration, and will be a decisive factor as to how the work should be done, or if it can be done at all.

A few examples are given below of openings that can be made in different types of roofs commonly found in Sweden. It is a good exercise to make an inventory and to go through the different types of roofs/structures that may be encountered in fire and rescue operations.

It is also important to bear in mind that the actual opening should be made in such a way that there is always a safe escape route, as described in the last chapter. The first cut in a roof should be made away from the work platform (ladder or ladder truck), so that the last cut can be made while standing on this work platform.

Tin plated roofs on older buildings



Cross section of tin plated roof structure.

The tin plated roof is built up as follows, from the inside to the outside:

- wooden roof trusses
- wooden roof boarding
- roof base paste board, where appropriate
- seamed metal sheeting

The opening is made between the roof trusses. On roofs with seamed metal sheeting it is difficult to see where the roof trusses are. On certain buildings they may extrude at the base of the roof. There is often metal jointing or other metal objects just beside the roof trusses, ridge and base of the roof. Leave an edge of one to two decimetres from these.

To make an opening for fire ventilation the seamed metal sheeting can be penetrated in different ways. One way is to cut it by means of a power cutter, and if the power cutter is powerful enough it will also be possible to saw through the roof boarding at the same time. For the power cutter to work effectively it must be run at full speed. It should work

its way through on its own, without using excessive manual force. If the roof boarding is not removed at the same time it can be sawn when the metal sheeting has been removed, for example with a chainsaw or circular saw.

One advantage of removing the metal sheeting first, and then sawing the roof boarding, is that the nails become exposed at the roof trusses, which makes it easy to locate the roof trusses. Another method of removing the metal sheeting is to knock up the seams with a club or a large hammer. Once the seams round the sheeting have been knocked up, it can be lifted or pulled off. If the sheeting jams so that it is difficult to remove, an extractor tool can be used. The sheet metal extractor's chain can be fixed in the lever basket so that the metal sheeting can then be lifted off with the lever.

Openings made in tin plated roof with power cutter. The seams are knocked up with a hammer before the sheeting is removed.

Tiled roofs

Cross section of tiled roof structure.

The tiled roof is built up as follows, from the inside to the outside:

- wooden roof trusses
- roof boarding
- roofing felt
- battens
- roof tiles

The roof tiles are removed from the place where the opening is to be made. The opening is made between the roof trusses, with a remaining edge of about two decimetres to the roof trusses, ridge and base of the roof. The location of the roof trusses is easily determined on structures where they protrude from the base of the roof, otherwise the nails can be exposed by removing the roofing felt. It is also possible to determine the location of the roof trusses by tapping with a hammer on the roof boarding and listening to where it sounds most hollow.

Once the tiles are removed the opening can be made by sawing through the roof boarding with a power cutter, a chainsaw or a circular saw. The easiest thing is to start at the ridge, and then saw the edges of the opening and finally along the base of the roof. A jimmy or crowbar is often needed to remove the roof boarding and battens completely.

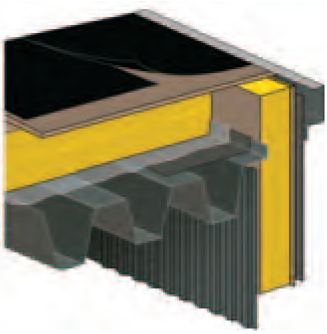
Loose tiles pose a special risk with tiled roofs, and can drop down on personnel standing on the ground or on a ladder. In the case of an intense fire roof tiles can be blown off, and therefore personnel, vehicles and equipment should be placed at a safe distance from the building. The roof tiles that are removed should be placed on the ground. On older buildings the roof tiles may be attached to the battens or roof boarding with a cut-off nail that sticks out one or two centimetres. When the roof tiles have been removed it is easy to injure oneself on these nails when making an opening, or when balancing oneself against the roof.

Roofs with tarred roofing felt/waterproof paper roof

Tarred roofing felt can be laid on mineral wool boarding, roof boarding or the like, and can be difficult to identify from the outside. Below this there is often insulation, and below the insulation the supporting structure. This can be roof trusses, or corrugated metal sheeting laid on steel girders (see next section).

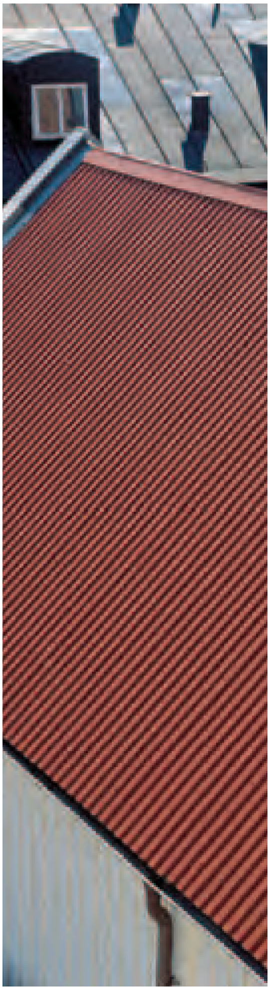
It can be difficult to get through tarred roofing felt. If a chainsaw is used the tar can cause the chain to stick. A power cutter with emergency blade can manage to cut through, but to avoid the problem the tarred roofing felt can be removed with a scraper where the cuts are to be made.

Make an opening in the surface under the roofing felt, and remove the insulation. The location of the roof trusses or the supporting girders can then be determined.



Cross section of roof with covering of tarred roofing felt.

Below: Using a scraper.



Roofs with corrugated metal sheeting

A roof with corrugated metal sheeting can consist of, from the inside to the outside:

- profiled metal sheeting
- plastic sheeting
- insulation (mineral wool, rock wool or cellular plastic)
- possibly asphalt boarding, possibly also with felt
- profiled metal sheeting

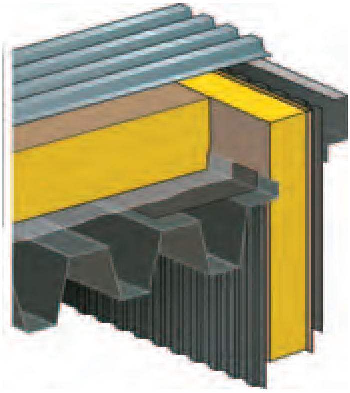
In such a structure the interior metal sheeting provides the support and is laid on steel girders.

To make an opening for fire ventilation both the outer and inner profiled metal sheeting must be cut through. The outer profiled metal sheeting is often not as deeply profiled, and can therefore be sawn with a power cutter. Another alternative can be to use a sheet metal extractor, but this assumes that the attachments can be broken without using too much force. Perhaps the easier way of removing the outer profiled metal sheeting is to use a screwdriver. The fastenings can be removed with a battery operated drilling machine fitting with a fixed socket or a screwdriver bit. The sheeting can then easily be removed and lifted down. If the sheeting is fastened with screws it is relatively easy to make a large opening in the outer roof.

Sheet metal extractor.

It is a good idea if the outer opening is oversized to facilitate making the inner opening for fire ventilation. The following method can be used to gain access with the power cutter in the grooves of the metal sheeting:

1. Saw two parallel slots across the grooves of the sheeting. The space between them should be wider than the power cutter.
2. Press down the sheeting between the slots.
3. Saw the sheeting in the bottom of the grooves.
4. Do the same thing on the other side of the opening.
5. Saw the short sides of the opening up on a seam in the sheeting. If these slots are sawn first this increases the risk of falling through when the sheeting between the two parallel slots is to be pressed down.



Cross section of roof with corrugated metal sheeting.

1.

2.

3.

If the sheeting is fastened with screws to each other and in the girders, it can be relatively easy to remove a complete sheeting instead of sawing up the opening.

Special problems with this type of roof include melting tar from the tarred roof base paste board running down in the bottom of the grooves in the sheeting. If the roof is also at an angle the fire can therefore spread under the insulation. The roofing felt and insulation should therefore be removed a good bit from the ventilation opening. If the roof is so hot that the tar melts before an opening has been made for fire ventilation, an opening should be made instead to prevent the spread of the fire in the roof structure. Bear in mind that tar runs quickly, and also that the separation at fire compartments limits beneath the metal sheeting may not be very well executed on this type of roof.

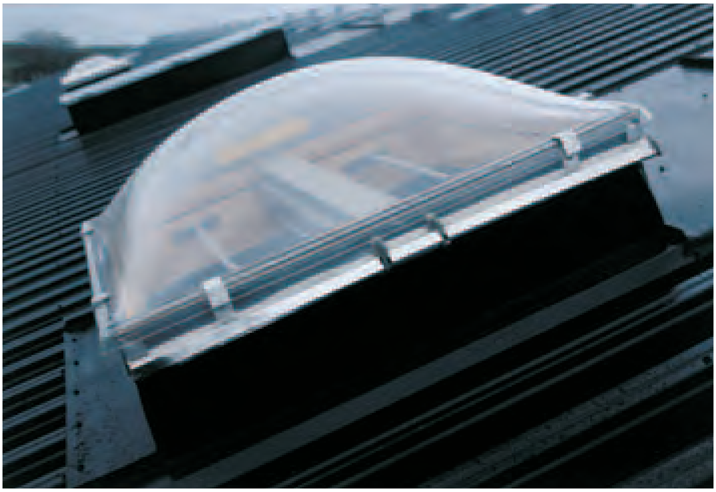
Permanent installations for fire ventilation

Smoke vents

In industrial buildings there are often so-called smoke vents. They are normally designed to allow fire gases to escape by means of its thermal buoyancy force, and can be designed as cowls with shutters or as light apertures. The vents are opened automatically or manually during a fire. If they open automatically they will either by connected to an automatic fire alarm, or there will be a fusible plate. The fusible plate consists of two soldered metals that will melt at a certain temperature, whereby the vent opens. In older buildings there can be a nitrated wire instead of a fusible plate, which burns off at a relatively moderate temperature. Neither fusible plates not nitrated wires are particularly common.

In cowsheds and stables the smoke vents can consist of plastic sheets (light apertures), which are intended to be burned through at an early stage of the fire.

Smoke vents that are opened manually can be opened by means of a switch/knob, for example in the fire alarm central. The shutters on the smoke vents are kept shut be means of magnets, and open when the power is switched off. Another alternative is that there is a handle on the vent, connected to a locking device. The shutter is opened by turning the handle.



Vents are often used as light apertures in industrial, craft or storage premises. They can be opened manually or automatically.

A completely manual shutter, often in the form of a light aperture, must be opened by removing the securing plate and lifting the shutter off. In this case a hammer, screwdriver or jimmy (crowbar) is often needed.

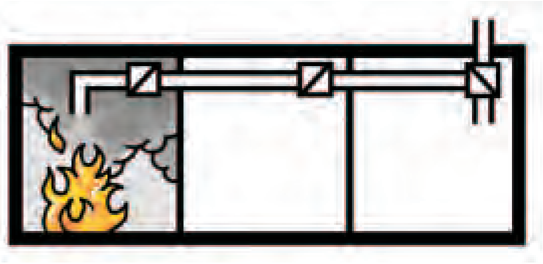
Mechanical ventilation

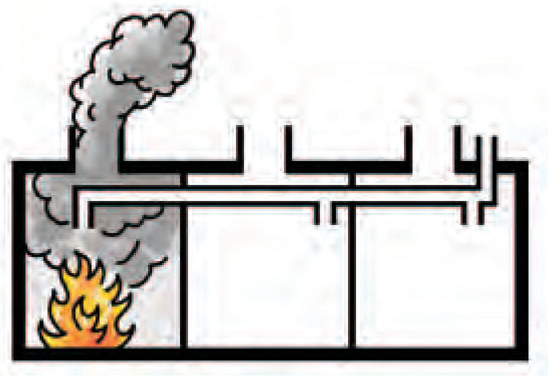
Ventilation systems in buildings are normally designed so that the spread of fire and fire gases is prevented, for example by insulating the ducts. But ventilation systems can also in certain cases be dimensioned and used to more actively contribute towards simplifying evacuation and the fire and rescue operation. Smoke management – the management and control of smoke – is a common term in this content, and is an overall concept to provide for the safety of people, to limit damage to property, and to simplify the work of the rescue services. Part of this overall concept can consist of designing mechanical ventilation systems to:

- facilitate evacuation
- prevent or limit the spread of fire gases in the building
- facilitate the fire fighting operation.

The possibility of using mechanical ventilation systems as an active part of the structural fire safety in buildings is limited by the type of building. A building with a large number of small and separate rooms is less suitable. On the other hand the method is feasible for covered yards, shopping malls, assembly halls, industrial workshops or warehouses. Two principles are normally used in these systems: pressure relief and pressurising, often in combination.

Pressure relief is normally a measure directed towards the fire room, for example in large areas such as assembly halls and industrial buildings. Pressure relief takes place by opening one or more shutters or windows so that the fire gases can flow out (see section above on smoke vents). Another solution is that pressure relief is done through separate shafts. Both shafts and shutters (smoke vents) can be fitted with a fan resistant to high temperatures, which starts when the system is activated during a fire.





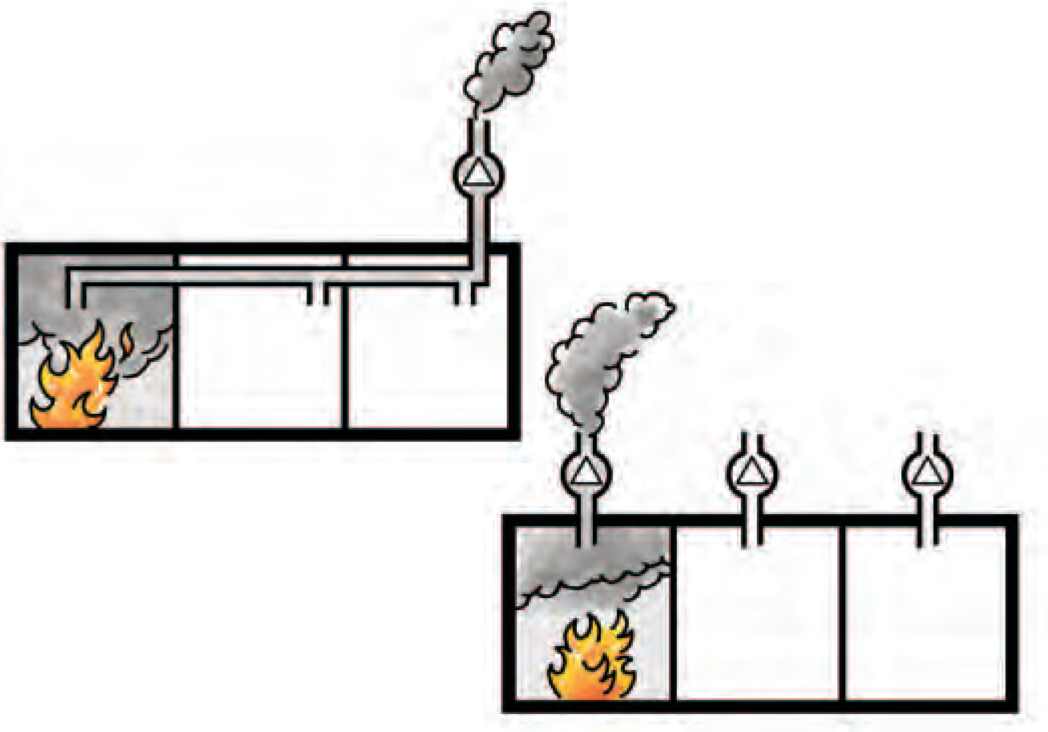
Examples of different systems for controlling supply and exhaust air flows by means of detection systems and dampers.

Pressurising can be used as an alternative, or supplement, to pressure relief. This measure is used in adjacent areas, for example evacuation routes (stairwells, corridors and the like). The main purpose of this measure is to facilitate evacuation and the fire and rescue operation. A pressurising system can be integrated with the comfort ventilation, or alternatively be implemented as a separate system.

In integrated systems the comfort ventilation system can be controlled by means of detectors so that the fire room is put under negative pressure (the supply air is switched off), while the exhaust air in adjacent rooms is switched off.

In systems especially intended for pressurisation there is a separate fan system, which starts during a fire and puts certain areas, for example evacuation routes, under positive pressure. If such a system is put into operation the building's normal ventilation system is switched off.

To facilitate evacuation it is important that the mechanical ventilation systems are started at an early stage, and for



In buildings that have systems for pressurising (positive or negative pressure) it should be borne in mind that:

- Stairwells are not always placed in connection with outer walls.
- The sectioning of evacuation routes can be simplified.
- Evacuation routes can be longer than normal.
- The number of stairwells can be limited.
- The system can make doors difficult to open or close.

this reason they are normally connected to an automatic fire alarm. The system starts when a fire is detected. In certain cases, however, the system may need to be manually controlled, i.e. someone has to start the system with a switch or the like.

CHAPTER 9

Tactics

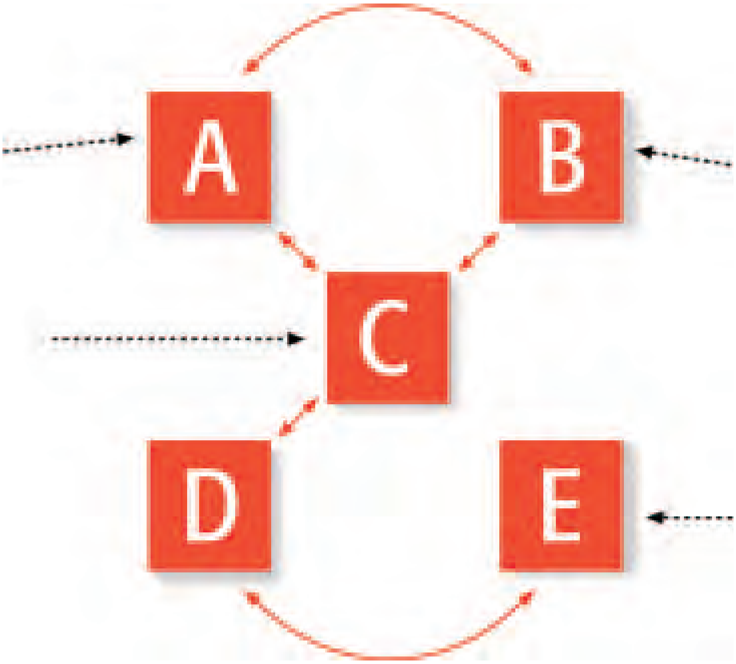
Tactics can be said to be, doing the right things at the right time. One definition of rescue tactics, i.e. tactics in association with fire and rescue operations, that has been used in Sweden in recent years says that rescue tactics can be seen as a pattern of thought and action to achieve the best possible results on the basis of the overall purpose of preventing or limiting injuries to people, or damage to property or the environment.

Tactics is about using resources as effectively as possible in relation to the need for assistance, the dynamics of the situation and the other demands posed by the situation, with a view to achieving and maintaining control. Tactics therefore describe what and how something should be done, not who does it.

When resources are used in different ways, for example at the scene of an accident, certain measures are initiated, coordinated and implemented. Measures are therefore implemented by resources that are allocated tasks. In certain cases the resource is designated as a unit that is an organisational support for the resource, i.e. that the resource is linked to a certain place in an organisation. Such a unit normally consists of both people (personnel) and machines (technical aids). Measures are therefore produced by the help of units. Both the number of people and the amount of machinery and other equipment the unit consists of can vary. Units are defined in advance, before fire and rescue operations are implemented.

Tactics
Tactics are about how the different parts in a fire and rescue operation are put together, structured and form an overall solution. This overall solution is part of a wider context, and should be arranged in the best possible way.

As a rule several measures are implemented at the same time. It can be said that the measures are put together in



The measures that are initiated, coordinated and implemented in association with fire and rescue operations are put together in tactical patterns, where they are linked to each other and depend on each in different ways. They are also part of a specific context.

tactical patterns, where several different measures are linked to each other and depend on each other in different ways. This for example can be the case with positive pressure ventilation, where the positioning of fans is coordinated with the creation of outlets and internal fire suppression.

Measures are also initiated, coordinated and implemented in a specific context. The context is important to determine which measures, taking everything into consideration, must, can or should be initiated, coordinated and implemented, and in which order this must, can or should be done. It is therefore essential to be able to identify the context and the problems that must be solved in the short and long term. The context therefore influences both the choice of measures and in which way or in which order they are initiated, coordinated and implemented in the tactical pattern. When this concerns fire ventilation the context is among other things the identification and understanding of which pressure forces have to be handled, and what the pressure conditions look like inside the building.

The measures that are initiated, coordinated and implemented create, together with the accident scenario, a dynamic relationship, i.e. dependency in time and space, between different types of measures, between respective measures and the accident scenario, and between the tactical pattern and the accident scenario. It should also be borne in mind that the accident scenario will continue regardless of whether measures are initiated, coordinated and implemented or not. It is from these dynamics, i.e. the interaction between the measures and the accident, that tactics develop. Tactics are therefore what connect the measures to the accident scenario. In the case of fire ventilation, for example, consideration must be taken to the time it takes to create openings in relation to how the fire develops. It is important that measures are initiated in good time.

It is of great importance that everyone involved in fire and rescue operations has first-rate knowledge of the dynamics that affect the way accidents develop and the chain of events, regardless of whether measures are taken or not. It is also important to link these dynamics to the impact accidents have on the people affected, property or the environment, since it is the need for assistance as a result of an accident or imminent danger of an accident that must be in focus. It should also be borne in mind that in some cases fire ventilation can lead to an undesired sequence of events and impact on people, property or the environment.

It is possible to define an overall purpose for fire and rescue operations – to achieve and maintain control. To achieve and maintain control it is usually necessary to satisfy four general conditions:

- There must be a goal (the goal condition)
- It must be possible to ascertain the state of the system to be controlled (the observability condition)
- It must be possible to change the state of the system (the change condition)
- There must be a model of the system that describes what will happen if we do something to the system (the model condition)

It is only through control that a sequence of events can be guided in the intended direction, and it is by initiating, coordinating and implementing measures that control is achieved and maintained.

Fire ventilation is a collective concept for several different types of measures, with the common objective of venting out fire gases. Depending on what the purpose is in a specific situation, one or more ventilation measures are implemented. This is part of the goal condition to achieve and maintain control – fire ventilation must have a goal. The observability condition will tell us, depending on the context and which resources (units) are available, that fire ventilation can be implemented in different ways, i.e. in different tactical patterns. It may, for example, in certain situations be better to vent first and then make a traditional attack, while in other situations it might not be possible to vent until a much later stage in the operation. Sometimes it is perhaps better not to vent at all. To a large extent this depends on the context. If the goal is to vent out fire gases, it must also be possible to change the state of the system – it must be possible to effect a change in the intended way with the help of fire ventilation.

Fire ventilation is only part of the measures that normally need to be implemented, and such ventilation often needs to be combined with other measures to ensure the best possible results.

Tactics is about using resources as effectively as possible in relation to the need for assistance, the dynamics of the situation and the other demands posed by the situation, with a view to achieving and maintaining control.

CHAPTER 10

Examples of fire fighting situations

Earlier in this book fire ventilation has been treated as a separate measure. It is, however, important to link fire ventilation with other parts of the fire and rescue operation, depending among other things on what the fire looks like, what the building/fire room looks like, and which resources are available.

A number of conceivable fire and rescue operations are described below, where fire ventilation can be an appropriate measure. The exemplified situations have been refined to demonstrate the issues, problems and possibilities applicable to fire ventilation. In real fires it is seldom as simple as this. Above all there is a time factor to be taken into consideration, which is difficult to describe in a text of this nature. The intention of the examples is only to create a picture of how several different, but conceivable situations may develop.

Small fire in relation to the size of the room

If the fire is small in relation to the size of the room the fire will seldom develop into a fully developed fire, even if the fire is fuel controlled all the time. The fire may, however, develop a large volume of fire gases that needs to be vented out.

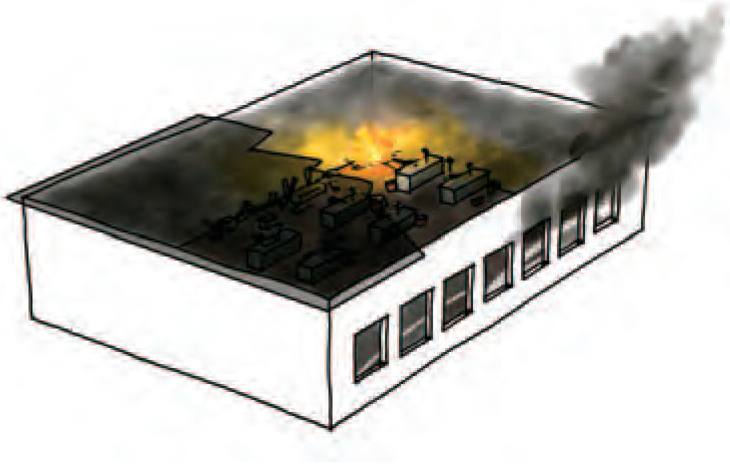
This could be the case, for example, in a large industrial premise with a relatively contained fire, or if there is a high ceiling. The higher the ceiling, the greater the volume of air that will be mixed in with the products from the fire. There will therefore be a large volume of fire gases, but it will be relatively cold and diluted. Because of the size of the room the fire will be fuel controlled for a long period, and may not become ventilation controlled at all.

The risks associated with fire ventilation are very small in this situation.

It is also conceivable that a similar situation will occur in the case of apartment fires. The interior ceiling and walls may be incombustible (e.g. plasterboard) and if the interior furnishings (furniture etc.) are placed in such way that a fire in an individual object does not spread to other objects, the fire can remain fuel controlled during the entire fire scenario. It may self-extinguish when the fuel is used up. The risks associated with fire ventilation in these situations are also very small.

Small fires can, however, develop quickly and powerfully during fire ventilation if they are located in double flooring, ceilings, under floor areas, or confined in other ways in what is otherwise a large room. This sets extensive tactical requirements, above all in the form of the build-up of resources. Even if the room is well ventilated there can be concealed areas that are poorly ventilated.

Since the fire gases has a relatively low temperature and very limited buoyancy force, an opening for an outlet should be made as high up as possible, preferably in the roof. Supply air should be taken from the lowest possible point, and mechanical ventilation should be carried out. Negative pressure ventilation can as a result of practical problems be difficult to implement, especially if the room is very large. It may also be difficult



A small fire in a large room causes the smoke to have a low temperature and therefore it can be difficult to vent, both with and without fans.

To be taken into consideration in the case of a small fire in relation to the size of the room:

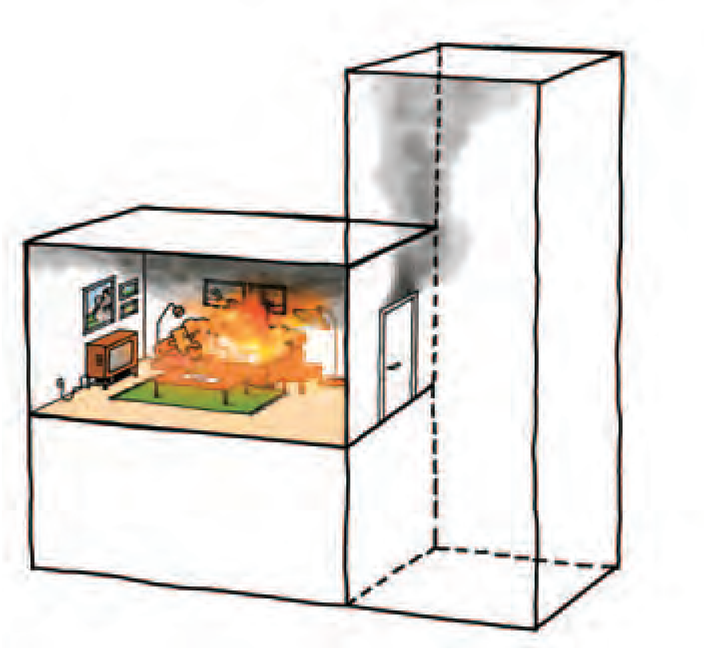
- If the room is very large, a large air flow will be required to maintain sufficient positive pressure. Fans on the supply air side could also create large problems, since the stratification of the smoke can be interfered with so that it is spread throughout the room.
- Long access routes make it more difficult to locate the source of the fire.
- At high wind speeds (more than 5–8 m/s) the positioning of inlets and outlets should be selected so that they interact with the mechanical ventilation.

to use positive pressure ventilation since the flow of supply air creates turbulence, which can interfere with the stratification of the hot gases. Because of the size of the room it can take a long time to implement positive pressure ventilation, which makes things more difficult for the fire fighting crew.

The initial stage of the fire

The fire may still be in its initial stage when the rescue services arrive, for example if the fire is discovered and the alarm given quickly, or if it takes them little time to arrive, or also in the case of certain types of premises with relatively low fire-load densities. The fire gases can be hot, flashover has still not taken place, and the inlets permit a relatively free inflow of air. Hot gases flows out through the upper parts of openings, and fresh air flows in through the lower parts. The fire scenario can be very stable, stationary, very intensive or alternate rapidly, depending on the geometry of the premises, the position of the fuel, or the material in the ceilings and walls.

Since the fire gases are hot it is possible to use natural ventilation with satisfactory results. This involves creating openings in the upper part (roof) of the fire room/building



Flashover has still not taken place and the risks associated with fire ventilation are small.

and making sure that the inlets are at least 1–2 times larger than the outlets.

Positive pressure ventilation can be used to improve the effect of the openings. Positive pressure ventilation also reduces the requirement for the positioning of the outlets. For positive pressure ventilation the outlets should be 1–2 times larger than the inlets.

Because of the increased supply of air during fire ventilation, and because the combustible material and surfaces in the rooms have been heated up, the fire can quickly increase

To take into consideration during the initial stage of the fire:

- Select outlets carefully, since combustible gases can ignite in the openings.
- Observe the change in the situation for a short while before any fire fighting operations are started.
- Implement a rapid suppression operation to avoid an increase in the intensity of the fire.
- Use positive pressure ventilation where appropriate to enable a more rapid suppression/life saving operation.

in intensity. At some point flashover may also occur. This implies certain risks that the fire is still in the initial stage, but it can also be a considerable advantage. This advantage should be utilised, above all through rapid action.

Fully developed fire

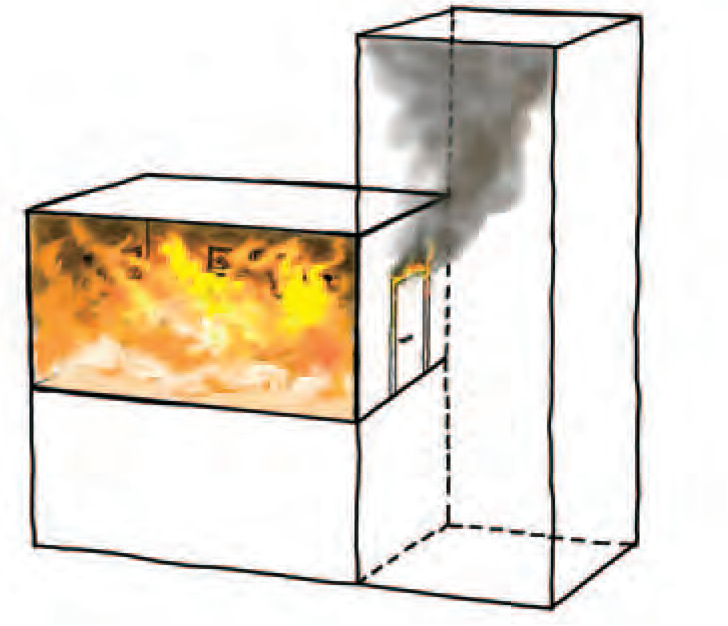
In many cases the fire is fully developed when the rescue services arrive. Flames are bursting out through openings and there can be an imminent risk of the fire spreading to adjacent rooms or buildings.

Life saving operations or fire ventilation are usually no longer an issue in the room, or rooms where flashover has taken place and where the fire is fully developed. In adjacent rooms, however, this can be motivated and of the highest priority. This is where fire ventilation can simplify the situation for both persons in distress and fire fighters.

Since the fire gases is hot it is possible to use natural/thermal ventilation with satisfactory results, i.e. openings should be made in the upper part of the room/building (roof) and the inlets should be at least 1–2 times larger than the outlets.

Positive pressure ventilation can be used to improve the effect of the openings. Positive pressure ventilation reduces the requirement for the positioning of the outlets. To utilise the thermal buoyancy force they should, however, be in the upper part of the building, and this will reduce the risk of the fire or fire gases spreading to adjacent rooms. For positive pressure ventilation the outlets should be 1–2 times larger than the inlets.

It is not taken for granted that venting should be done in the actual fire room. Since the fire is ventilation controlled, the intensity of the fire will further increase if openings are made. If openings are closed instead, this will reduce the intensity of the fire. In certain situations, if suppression has for various reasons been excluded as a first measure, it can therefore be more beneficial to attempt to shut in the fire and vent adjacent rooms instead. This can, for example, be a suitable measure when no resources are available for a



Flashover has taken place and the fire is fully developed. There is an imminent risk of the fire spreading.

direct attack on the fire, since the saving of lives in adjacent rooms must come first. One prerequisite is of course that the openings can be closed, which can be difficult or in fact impossible if windows have been broken, or if the roof or walls have burned up.

Other methods that should be taken into consideration can be filling the fire rooms that are not excessively large with medium expansion foam, or filling adjacent rooms with high expansion foam.

In the case of a fully developed fire, the risks and the problems are often quite obvious. The fire gases burns in contact with the air, and the entire fire room is involved. The primary tasks for the rescue services should, apart from saving lives, consist of preventing the spread of the fire and the fire gases.

To take into consideration during a fully developed fire:

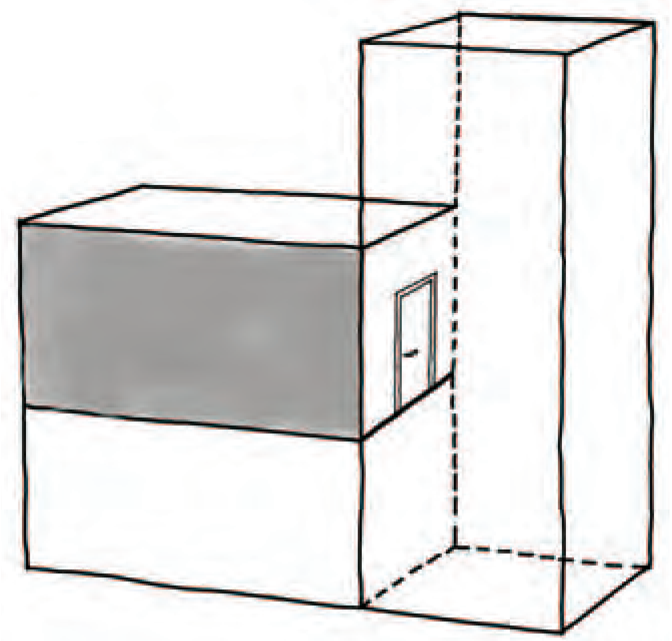
- Observe great care during the choice of outlets, in view of the flames that come out from the fire room.
- Have a well-planned and coordinated ventilation and suppression operation, since the supply of air will increase the intensity of the fire.
- Consider alternative methods.

Ventilation-controlled fire

In the case of a ventilation-controlled fire the fire scenario has developed towards flashover, but then diminished and reduced in intensity as a result of the lack of oxygen. The fire is, however, not fully extinguished and can sometimes maintain a high smoke temperature in the magnitude of 200–400°C. Large volumes of uncombusted gases can therefore be produced. The concentration of these varies, but can often be sufficient for them to start burning if air is supplied. If fire ventilation is implemented it is possible for a rapid flashover to take place, and the risk of backdraft can be imminent. This requires special conditions, however.

No doors or windows are open in this case, and the exchange of air can only take place through small leakage areas, for example through comfort ventilation. Large volumes of uncombusted gases can also spread to adjoining areas.

The purpose of fire ventilation for poorly ventilated rooms can be to force the fire scenario and to allow flashover to take place under controlled conditions. It can also be to reduce the spread of fire gases by reducing the pressure build-up of hot gases in the fire room or adjoining rooms.



The entire area is full of fire gases. Air can flow in if the fire room is opened and a potential ignition could take place rapidly, causing a considerable pressure wave.

Piercing nozzle (fog nail).

Alternatives or supplements to fire ventilation, for example the use of piercing nozzles, should be considered when the fire is strongly ventilation controlled.
If the fire gases can be cooled down in this way it will be possible to implement fire ventilation or internal suppression with significantly less risks. Filling with foam can be another alternative, which however assumes that the requisite opening can be made. The size of such an opening is often less than what would be needed for fire ventilation. It can often be appropriate to first secure the adjacent rooms or buildings before measures are taken for the fire room. In the case of ventilation-controlled fires it can be possible to save lives in the fire room, since the impact of the heat on trapped persons can be relatively moderate.

Ventilation-controlled fires involve large risks, since the fire gases contains large volumes of uncombusted gases. In the event of rapid mixing of large volumes of air there is a risk of backdraft. Above all there is a risk of very rapid flashover scenarios when fire ventilation is implemented.

To take into consideration during ventilation-controlled fires:

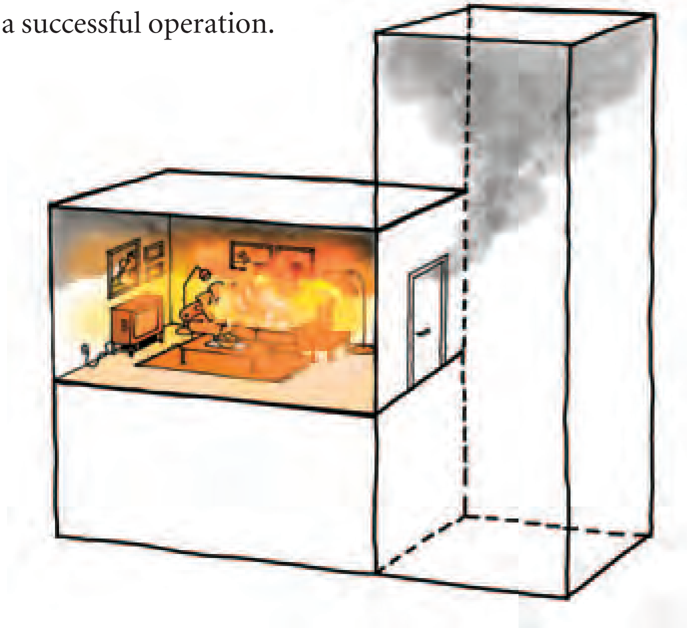
- Consider alternatives or supplementary methods to fire ventilation, for example cooling of the hot gases with piercing nozzles.
- Observe great care during the implementation of fire ventilation.
- Observe great care during the choice of outlets, both in view of flames that can come out from the fire area and a possible backdraft.
- Avoid turbulent mixing of fresh air in the fire gases.
- Have a well-planned and coordinated ventilation and suppression operation, since the supply of air will increase the intensity of the fire and the risk of spreading the fire and fire gases.

Stairwells with hot gases

During apartment fires relatively hot fire gases can in certain cases flow out into the stairwell. The stratification in the stairwell becomes apparent, with an upper area filled with fire gases and a lower area more or less free from fire gases. Evacuation from the upper apartments can be difficult to achieve.

Without some form of ventilation measure, and with closed doors, there will be a negative pressure in the bottom parts of the stairwell and a positive pressure in the upper parts. Fire gases can flow into the upper apartments, as a result among other things of the type of comfort ventilation and the temperature of the fire gases.

Since the fire gases has a relatively high temperature it is possible to use natural ventilation with satisfactory results. This assumes, however, that there is an openable hatch or window in the upper part of the stairwell, which is often the case. If positive pressure ventilation is used and the fan is placed at ground level outside the stairwell, the entire stairwell can be pressurised (see figure below) with a greater risk of the fire gases being forced into the upper apartments. If positive pressure ventilation is properly coordinated with the extinguishing operation for the apartment fire there are, however, the prerequisites for a successful operation.



The upper part of the stairwell is full of hot fire gases.

To take into consideration at stairwells containing hot fire gases:

- If there are people still remaining in the apartments connected to the upper part of the stairwell, the fire and rescue operation must be carefully planned in view of the fact that fire gases can flow into these apartments.
- During a fire and rescue operation for an apartment fire the spread of fire gases to the stairwell can be reduced by arranging fire ventilation from the apartment on fire, for example, through the window. The effect of this can be considerably improved with the help of positive pressure ventilation. If an apartment door in the upper part of the stairwell is opened by evacuating people, this apartment will quickly be filled with fire gases. This will also lead to a sudden pressure drop in the stairwell, and the outlet through the stairwell's roof hatch/window will be less effective.
- Alternative access routes, windows or balconies, should be considered when the spread of fire gases to the stairwell can be minimised by keeping the door to the apartment on fire closed.
- The risk of flashover or the spread of flames to the stairwell must be taken into consideration.

Stairwells with cold fire gases

During apartment fires it is possible, if the intensity of the fire is small in relation to the size of the apartment on fire, for fire gases with a relatively low temperature to flow into the stairwell. Alternatively, a relatively small volume of hot fire gases can be mixed with fresh air and cooled as it penetrates out into the stairwell. In this case there will be no apparent stratification in the stairwell.

Natural ventilation will have little effect and an opening made in the upper part of the stairwell should be supplemented with positive pressure ventilation. The prerequisites for positive pressure ventilation, i.e. coordinated with

The stairwell is full of cold smoke, which can be difficult to vent out.

an extinguishing operation, are in this case positive, since the operation can be implemented with only a limited spread of fire gases to the stairwell. This requires, however, making an opening in the apartment on fire (outlet).

To take into consideration at stairwells containing cold fire gases:

- If an apartment door in the upper part of the stairwell is opened by evacuating people, fire gases can quickly spread to this apartment. The fire gases will, however, be cold and diluted, which means that people in other apartments will be less exposed to risk. If an apartment door is opened this will also lead to a pressure drop in the stairwell, and both the outlet through the roof of the stairwell and any positive pressure ventilation will be less effective.
- During the summer problems can arise if it is warmer outside than inside the stairwell, even if the stairwell is filled with fire gases. It is then conceivable that fire gases will collect in the bottom of the stairwell, especially in very high buildings.

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the author's home page

List of figures

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