Preventing smoke spread with the ventilation system in operation

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SUMMARY

The view on risk of smoke spread in ventilations systems varies throughout Europe. In some countries smoke spread via the ventilation system is not considered to be a problem at all, in other countries smoke dampers or fire/smoke dampers are always required where there are more than one fire compartment supplied by the same system. Finally there are countries where the regulations in addition to fire/smoke dampers also allow performance-based design.

In Sweden there are three different methods for preventing smoke spread:

1. Separate ventilation system for each fire compartment
2. Fire/smoke dampers, activated with smoke detectors
3. Fans in operation during a fire

Designing the ventilation system to have fans in operation to prevent or limit smoke spread is a commonly used performance based design method that does not require smoke dampers.

In 2002 the Swedish authorities introduced general recommendations on analytic design, BBRAD. The recommendation states how verification by analytical design should be performed and what methods and criteria to be used.

Using these criteria and a computer model of the ventilation system it can be determined if and how smoke spread occurs in a specific ventilation system. It is now possible to adjust the system in detail, setting the pressure drops at an optimum level. This can, however, be very risky. Changes are made along the way and the constructed ventilation system ends up with a slightly different ductwork that might not give the protection against smoke spread that was intended.

It is therefore necessary to design a ventilation system that is robust enough to handle minor changes or adjustments made by the contractor, or for that matter, changes made in future reconstructions. Furthermore, creating a robust system, advanced calculations might not need to be used to verify the system. Simple calculations by hand could be enough.

Using the ordinary ventilation system in operation to prevent smoke spread is cost effective, both regarding construction costs and regarding the continuous maintenance. It is a reliable system since it is always in operation when there are people in the facilities and it is flexible. Given that the system constructed is a robust system changes can be made in architectural planning without need to change the ventilation system. Finally there already are methods and criteria available for designing engineers. No one needs to reinvent the wheel.
INTRODUCTION

This paper describes how a ventilation system can be designed to prevent smoke spread with the ventilation system in operation and appoints the advantages and difficulties of the method. It also gives a description of the Swedish building code in regards to smoke spread.

In most countries buildings have some kind of heating, ventilation and air conditioning system (HVAC). The type of ventilation and complexity varies, mainly due to differences in climate and tradition. It spans from a simple air conditioning unit mounted on the wall to a complex system using ducts to supply the entire building with heat, air conditioning and fresh air. All controlled by advanced technology. In Sweden, a majority of the buildings have some kind of mechanical ventilation with ductwork connecting different parts of the building.

There is also a difference between countries regarding fire compartmentation. In Sweden, for instance, each hotel room and each dwelling is its own fire compartment.

This paper focus on ventilation systems fitted with a fan and ductwork connecting several fire compartments.

The view on risk of smoke spread in ventilations systems varies throughout Europe. In some countries smoke spread via the ventilation system is not considered to be a problem at all, in other countries smoke dampers or fire/smoke dampers are always required where there are more than one fire compartment supplied by the same system. Finally there are countries where the regulations in addition to fire/smoke dampers also allow performance-based design.

In the report “Osäkerheter vid brandteknisk dimensionering av ventilationssystem, 2006”, Nils Johansson compares the regulations regarding smoke spread via ventilation systems in seven different countries; Norway, Denmark, Germany, England, USA and New Zealand.

The regulations in all of these countries allow performance based design. Furthermore they all state that ventilation systems shall be designed to ensure that the spread of fire and smoke between fire compartments is prevented.

Overall, using fire/smoke dampers is the most common method, in some countries the only method.

Using fire/smoke dampers can generate considerable costs in buildings with many fire compartments, such as hotels and dwellings. It is therefore of interest to find other methods to prevent smoke spread.

Designing the ventilation system to have fans in operation to prevent or limit smoke spread is a commonly used performance based design method that does not require smoke dampers. The absence of smoke dampers means lower construction costs and less maintenance. Furthermore it is a reliable system since the system always is in “fire mode”.

This paper only deals with fire and smoke spread in the exhaust air system. The supply air system is assumed to be equipped with special air stream operated dampers to each fire compartment. These dampers only allow airflow in one direction. They are less expensive than a fire/smoke damper and operate mechanically without any control systems.

NATIONAL REGULATIONS IN SWEDEN
In Sweden the issue of smoke spread via the ventilation systems has been dealt with, one way or another, in the regulations since the 1960’s. Back then the Swedish regulations (SBN 1967) stated that ducts from different fire compartments could be connected to the same ductwork, if precautions were taken to prevent fire and smoke spread.

Smoke spread via mechanical ventilation systems was prevented using the ordinary ductwork and fan, assuming that the pressure drop in the system was enough to prevent smoke spread. The fan was preferably located on the top floor and if the fan was not designed to easily let the air through when not in operation, the fan was fitted with a by-pass device. The by-pass was opened automatically when the temperature reached 50 degrees Celsius.

Dampers were only mentioned as a method to prevent fire spread, not smoke spread, and dampers were only to be used exceptionally - in buildings with routines for maintenance.

In 1994 the Swedish regulations were rewritten again, aiming for more performance based regulations. This was the first version of the regulations that we still have today, BBR.

We now have three methods for preventing smoke spread in Sweden:

1. Separate ventilation system for each fire compartment
2. Fire/smoke dampers, activated with smoke detectors
3. Fans in operation during a fire

In the first version of the current building code, BBR, it was now stated that smoke spread through the ventilation system should be prevented or, in some cases, limited/restricted. Using a fan in operation the ventilations system had to withstand a fire pressure of 1000 Pa and the loss of pressure over a part of the system serving one fire compartment was to be at least 1:3 of the pressure loss in the stub duct.

In 2002 the specific limit of 1000 Pa was no longer in the regulations, but then reappeared in October 2011, only now it was 1500 Pa. At the same time general recommendations on analytic design, BBRAD, were introduced. The recommendation states how verification by analytical design should be performed and what methods and criteria to be used.

Regarding verification of protection against smoke spread via the ventilation system, the following criteria for the early stage of the fire are given:

1. Fire growth rate of 0,047 kW/s². Lower growth rate can be used if it can be verified.
2. The pressure created by the temperature rise in the fire room is limited to a maximum of 1500 Pa. Lower pressure can be used if proven to be it can be verified.
3. The temperature in the early stage of the fire is limited to a maximum of 350 degrees Celsius.
Using these criteria and a computer model of the ventilation system it can be determined if and how smoke spread occurs in a specific ventilation system. It is now possible to adjust the system in detail, setting the pressure drops at an optimum level. This can, however, be very risky.

The duct system and the pressure drops used in the design of the system are most likely not going to be the same in the constructed system. Changes are made along the way. New bends and iris dampers may be added, causing extra pressure drops here and there. In the end it is a slightly different ductwork that might not give the protection against smoke spread that was intended.

To avoid this, the aim is to design a robust system. A system that can withstand minor changes without losing its ability to prevent smoke spread. Furthermore, creating a robust system, advanced calculations might not need to be used to verify the system. Simple calculations by hand could be enough.

**WHAT MAKES A VENTILATION SYSTEM ROBUST?**

What makes a ventilation system robust enough to handle minor changes or adjustments made by the contractor, or for that matter, changes made in future reconstructions?

In order to determine how to build a robust system it is important to look at the theory behind the smoke spread. What causes smoke spread via the ducts in the ventilation system?

**Theory**

The increasing temperature in the fire compartment causes the air to expand in volume and thus expansion increases the pressure in the compartment and drives some of the gas out of the room through leakages. The fire gas flow caused by temperature expansion of the heated gas in the fire room is referred to as "fire flow".

The fire flow mainly depends on the size of the air volume and the fire growth rate (energy per unit time).

The size of the pressure build-up that occurs in the room depends on the size of the fire flow and the airtightness of the room.

The airtightness can be considered equivalent to the leakage through the envelope surfaces, the pressure drop caused by ventilation devices including the duct system and normal flow in the ventilation system.

The increased pressure in the fire compartment causes the fire gases to be pushed out through leaks and into the supply air ducts and the exhaust air ducts in the ventilation system.

The fire flow will increase due to the growth of the fire until the oxygen in the fire room has been consumed to such an extent that the fire decreases, or until the window in the room is broken. Both of these phenomena normally occur before the temperature of the smoke gas reached 350 degrees Celsius.

Maximum fire flow from one compartment can be calculated using the formula (Gordonova, 1997):

\[ G = \frac{Q}{A} \]
In cases where the calculated fire flow results in a pressure exceeding 1500 Pa (the criteria set in the Swedish guideline BBRAD) the fire flow is reduced to a size corresponding to a pressure build-up of 1500 Pa.

When the window in the fire room brakes the fire flow is drastically reduced and the risk of smoke spread is significantly reduced. At this stage, however, flashover occurs in the fire room, leading to high temperatures. The smoke is sucked into the ventilation system by the fan or by thermal buoyancy. High temperatures will then affect the ducts, the fan and other components.

The friction losses in the duct system become greater at higher flows. This means that the pressure generated by the fire causes bigger pressure drops in iris dampers, bends and ducts. Especially in small ducts where there already is relatively high velocity this becomes apparent.

This is evident from the following formula which shows that the pressure drop ($\Delta p$) is 4 times greater at a doubled flow ($q$):

$$\Delta p_n = k_n \cdot q_n^2$$

**The robust ventilation system**

Given a high pressure in the fire room the fire flow into the ventilation system is of significant size.

The increased flow in the ducts will generate higher pressure drops over each component in the ventilations system. For instance, the fire flow from a room with a normal flow of 50 l/s and a pressure drop of 40 Pa will be 300 l/s.

In a duct with a normal flow of 50 l/s this fire flow will generate following approximate pressure drops:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Normal flow (l/s)</th>
<th>Pressure drop (Pa/m)</th>
<th>Fire flow (l/s)</th>
<th>Pressure drop Fire Pa/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>50</td>
<td>5</td>
<td>300</td>
<td>180</td>
</tr>
<tr>
<td>160</td>
<td>50</td>
<td>0.5</td>
<td>300</td>
<td>18</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>0.2</td>
<td>300</td>
<td>7</td>
</tr>
</tbody>
</table>

It is clear that the size of both the ducts and the normal pressure drops is significant for the ability of the ventilation system to take care of the fire flow.

Based on theory and experience from dimensioning different types of ventilation systems, it is possible to determine what makes a ventilation system robust.
An exhaust system with good conditions to be designed with fans operating has

- **Separate ducts from each compartment** connected to a box, preferably at least 4-5 ducts and equal normal flows.
- **The fan positioned at the top of the building** (high buildings)
- **Relatively large duct dimensions.** Maintain the same duct dimensions all the way out to the last fire compartment. Aim at low normal flow in the ducts, preferably 1-2 m/s.
- **No commissioning (adjustment) dampers** on ducts serving more than one compartment, i.e., we want all major pressure drops to occur directly at each fire compartment.
- **Relatively high pressure drop** to each fire compartment. Preferably in the order of 50-80 Pa.

The figures below illustrate ventilations systems with good conditions for protecting against smoke spread.

*Fig 1: Robust system with separate ducts, fan positioned at the top, relatively large duct dimensions, no commissioning (adjustment) dampers and a bypass device at the filter.*

*Fig 2: Robust system with separate ducts, relatively large duct dimensions and commissioning (adjustment) dampers positioned at each fire compartment.*

**Example**
The effect of the ordinary pressure drop on the smoke spread can be illustrated using a method for manual calculations called the “Alexander” method, named after Alexander the Great and myth of the Gordian knot. The method is developed by Lars Jensen.

At the very moment right before smoke spread occurs the flow from an adjacent compartment is 0 l/s. This is when the flow changes direction.

Assuming the flow into the other compartments is 0 l/s it is possible to estimate if smoke spread can occur, simply by using the formula described in the theory section.

First, use the ordinary pressure drops and flows of the system.

The pressure in “A” is -100 Pa. When the fire pressure pushes the fire flow into the duct the fan will no longer be able to sustain -100 Pa at “A”.

Set the flow in one of the branches to 0 l/s. In this case, the flow 0 l/s occur when the pressure at “A” reaches 0 Pa.

\[
q_{\text{fire}} = 1Q \cdot \sqrt{\frac{1500}{100}} = 4Q, \quad \text{the fire flow equals the ordinary flow at the fan, smoke spread will not occur.}
\]

Now try to change the ordinary pressure at “A” to 50 Pa.

\[
q_{\text{fire}} = 1Q \cdot \sqrt{\frac{1500}{50}} = 5.5Q > 4Q, \quad \text{smoke spread can occur}
\]
OTHER ISSUES TO CONSIDER USING FANS IN OPERATION

In addition to the design of the ductwork there are a few other issues to consider:

- Placement of supply air intake in relation to windows, exhaust air etc. Can smoke from a fire within the building spread via the air supply?
- Increased demands on fire insulation of the exhaust ducts.
- Demands on temperature resistance in the fan and other components such as cooker hoods, heat exchangers, ducts and commissioning dampers.
- The risk of clogging of filters, batteries and heat exchangers. A by-pass device might be needed at the filters.
- Controls that can stop the fan, such as frost protection devices or heat-recovery units.
- Demands on secure power supply, for instance fire resistant cable and distribution board. Consider the need of emergency power.
- Running operation. Is the ventilation system always in operation or is it sometimes shut down?
- Smoke spread in the supply air system. Preferably by fitting the supply ducts to each compartment with special air stream operated dampers, allowing flow in only one direction.

CHALLENGES/UNCERTAINTIES

Engineers designing ventilation systems and fire protection systems need to have knowledge and experience in order to design a robust system. Those who are already using the method need to share their knowledge and experience.

Designing the fire protection of the system takes more time and in order to verify protection against smoke spread the design of the system first has to be completed. This has to be taken into account planning the design process.

Not only does the design of the fire protection in the system take more time, it also has to take place earlier in the process, making sure there is room for by-passes etc. Fire/smoke dampers can be added rather late in the process, if there is room.

If the ventilation system is designed without robustness this could in the end result in a system that in reality does not fully protect against smoke spread. This can be avoided by addressing fire protection at the very start of the design process deciding the overall features such as placement of the fan and the ducts.

In areas where the power supply is unreliable it might be necessary to use emergency power for the fan.
STRENGTHS

There are many advantages using the ventilation system running compared to using fire/smoke dampers.

Using the ordinary ventilation system in operation to prevent smoke spread is cost effective, both regarding construction costs, mainly using the ordinary components in the ventilation system, and regarding the continuous maintenance since there are no fire components in the ductwork of the exhaust system. If there is a supply system there are probably air stream operated dampers controlling the direction of the flow, those dampers however need less maintenance than an ordinary fire/smoke damper.

It is a reliable system since it is always in operation when there are people in the facilities. The likelihood of people not noticing that the ventilation system is not running is considerably low.

A ventilation system with the system in operation is flexible. Given that the system constructed is a robust system changes can be made in architectural planning without need to change the ventilation system.

Finally there already are methods and critera available for designing engineers. No one needs to reinvent the wheel.

REFERENCES

1. Gordonova, Polina, *Spread of smoke and fire gases via the ventilation system*, Division of Building Science, Lund University, 1997
4. BBR 1, BFS 1993:57, Boverket, 1994
5. BBR 22, BFS 2011:6 med ändringar t.o.m. BFS 2015:3, Boverket, 2015