The smoke stopper

1 New fires, new problems, new solutions

The fact that fire behavior is changing, has become widely accepted in the fire service. New construction methods have resulted in fires not getting enough air before they progress into flashover. When a fire lacks air, it transitions from a fuel controlled burning regime into a ventilation controlled burning regime. If this transition, the FC/VC point, happens before flashover, then we are dealing with an under ventilated fire. A fire in which this transition happens during or close after flashover, is called a ventilated fire. To become a ventilated fire, there have to be sufficient openings (doors and windows) available. After all the fire needs to get enough air to develop.

Both types of fire behavior (ventilated and under ventilated) start out identically in the incipient stage. The fire is fuel controlled during this stage. It will start to consume oxygen and produce smoke. In a ventilated fire there will be a continuous supply of fresh air. Part of the smoke will also leave the compartment through the openings.

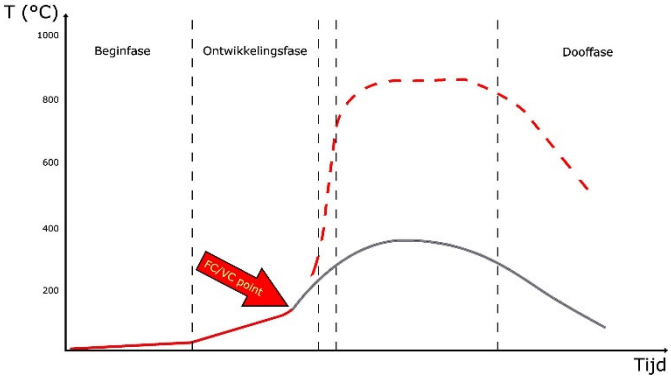

Figure 1 The ventilated (red dotted line) and the under ventilated fire development (gray). The FC/VC point marks the transition of a fuel controlled fire into a ventilation controlled fire. The FC/VC point that is indicated on the graph belongs to the gray line. The red dotted line also has its own FC/VC point. This is probably somewhere during or right after flashover. *(Graph: Karel Lambert)*

This isn't the case for the under ventilated fire. The oxygen percentage will drop more rapidly and the room will fill up swiftly with smoke. The smoke layer will start to drop down and the fire's intensity will decrease. Often when the fire service arrives, they are faced with a room that's completely filled up with smoke. As soon as the door is opened, both an outward flow of smoke and an inward flow of air are formed. Both of these flows will lead to disaster. The inward flow of air will cause the heat release rate to increase. On rare occasions this may lead to backdraft. Most often the fire will progress into a ventilation induced flashover. This poses a serious risk for firefighters.

The outward flow may also cause a lot of problems. This can happen both in an under ventilated fire and in a ventilated fire. A good example is that of a fully developed apartment fire on the second floor of the building. When the apartment door is opened, hot smoke and flames are flowing into the hallway. Hot smoke will start moving towards the central staircase. The staircase will start to fill up with smoke. However these stairs are also probably the only escape route available to the residents of the apartments above the fire floor. People looking out their window at the 10th floor will see exiting flames. When they decide to evacuate, they will first head into a rather clear hallway. As they descend the staircase, the smoke becomes thicker and hotter. Human nature will cause them to continue their descent of the stairs until they find themselves in dense, heavy smoke and

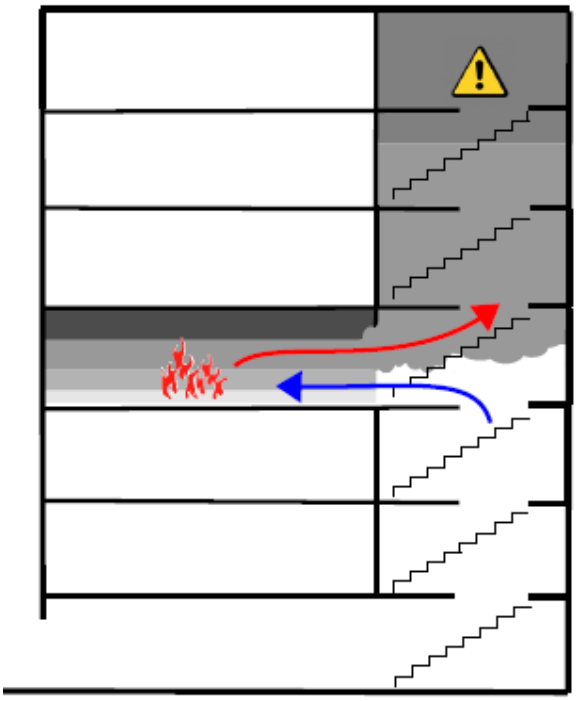

Figure 2 A fire on one of the lower floors of the building will have smoke flowing through the door into the staircase. Here, smoke concentration can reach a dangerously high level. This is one of the most important risks for building occupants. *(Illustration: Art Arnalich)*

they pass out. In Brussels there have been several cases where the fire service had to call for additional means (up to 4 medical teams) to save and treat these kind of victims.

Modern buildings often have a fire door in place between the staircase and the hallway and also a fire door leading from the apartment into the hallway. In buildings higher than 25m there even has to be a separate compartment so there are three fire doors between an apartment and the staircase. However in older buildings (predating new construction legislation) it is often the case that the apartment entry door is the only thing separating the staircase from the fire. In Chicago, a high rise fire caused the death of 6 people in the staircase. When the fire attack was initiated, the fire doors were opened. A large amount of smoke then flowed into the staircase. Six people became trapped and died of smoke inhalation.

A number of possible solutions to the problems formed by under ventilated fires has already been discussed in previous articles. Anti-ventilation means that the door leading into the compartment will remain closed up as much as possible. Typically the door will be closed up again to only just allow the hose line in, after the attack crew has made entry. A so called "door man" will keep the door closed and feed hose line into the room when necessary. This method will limit the outward flow of smoke. Suppose the opening left is 9 cm and the total door is 90 cm wide, the flow of smoke coming out is reduced to $1/10^{th}$ of what could normally be flowing out. The same naturally goes for the inward flow of fresh air. The opening of the door in this case is 9 cm wide and two meters high. The fire can only draw in air through the bottom end of this opening. If this is the only opening into the room, applying anti-ventilation will cause the heat release rate of the fire to be ten times less than when the door is completely open. This will severely reduce the risk of a ventilation induced flashover.

A second solution for under ventilated fires is the offensive exterior attack. This means that water is flowed in from the outside. Preferably this is done without making large openings because these would allow (too much) fresh air to be drawn in. There are several tools for this, like the cobra cold cutter and the piercing nozzle. These tools reduce the risk of rapid fire progress. When the temperature drops, the velocity at which smoke gas is flowing out, will decrease. However, this exiting smoke can still be a problem.

A third possibility to prevent smoke from spreading which is being tested, is pressurizing adjacent rooms and hallways. To achieve this result, positive pressure fans are pre-emptively set up. This is still a fairly new tactic, but there have been some successful

results in a few places. It is clear however, that further research is needed to determine what can and can't be done when applying this tactic.

Aside from pressurizing rooms, a fan can also create an air track. If the air track is sufficiently strong and if there's an outlet, it's possible that the entry door of the apartment becomes a unidirectional inlet. In that case, a large amount of air is being blown in and the outflow of smoke is being halted. This means that the fire will progress, but the problem of smoke in the hallway is solved. In practice, the effectiveness of this method will depend on the positioning of the fan, the measure in which doors of the non-involved rooms can be closed and the wind. Especially the last one, can have a devastating effect on this tactic.

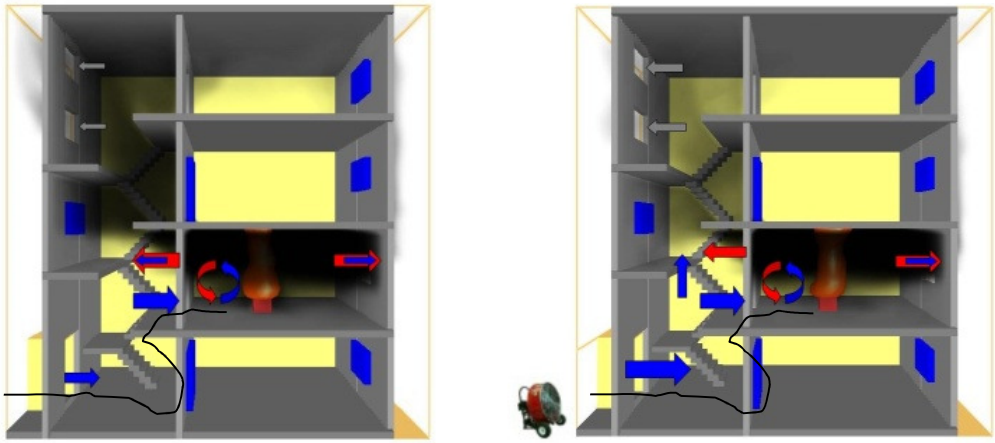

Figure 3 Comparison between a fire with or without a fan. The illustration on the left shows that the fire can burn freely and push smoke in the staircase. The illustration on the right shows the fan pushing the smoke back. The outward flow of smoke is severely limited. *(Graph: Michael Reick)*

In Germany professor Michael Reick has extensively studied the problem described above. Prof. Reick is a voluntary firefighter. He wondered whether it would possible to come up with a simple solution to protect neighboring rooms from smoke spread. He thought up the concept of the "smoke stopper". This article aims to take a closer look at the smoke stopper, it's deployment and it's possibilities.

2 The smoke stopper

2.1 Description

The smoke stopper is a very simple piece of equipment. It's a kind of curtain that's made out of the same material as a fire blanket. The aim is to use the curtain to close off the door opening. To achieve that goal, the smoke stopper has a built in positioning mechanism which can be used quickly and efficiently. The mechanism is made up of a frame that can be adjusted to the width of the door. In between the frame is an extensible rod. The principle of the rod is similar to that of anti-theft systems sometimes used in cars. There, a bar is placed in between the gas pedal and the steering wheel. The length of the bar can be adjusted. After the appropriate length has been chosen, the bar is locked.

Figure 4 Close up of the positioning mechanism of the smoke stopper. By pressing the clip the rod can be adjusted. Subsequently turning the bar in the direction of the arrow, adds tension which holds the device in place *(Photo: Karel Lambert)*

Added to this rod is a screw mechanism which allows for tension to be added manually. That way the top end of the curtain can be firmly fixed in the door frame. The upper end of the door will be completely sealed off. Gravity will then cause the curtain to seal off the lower end of the door. The curtain is hanging freely which allows it to move. This means that firefighters can move through it to enter the room.

If the door opening needs to be closed off even further, a second smoke stopper can be placed at a lower position. The door is then sealed off almost hermetically, but the disadvantage is that the door would also become impossible to be used as an entry point.

2.2 Positioning

The smoke stopper is normally placed in a carrier bag. Only when the door that has to be sealed is reached, is the smoke stopper removed from the bag. The curtain is fully stretched and the smoke stopper is placed in the door opening. A single firefighter can perform the positioning by himself. When placing the smoke stopper, the adjustable rod is fitted to the door frame. Next the rod is screwed tight so that the smoke stopper is firmly wedged in the door.

To achieve an optimum use of the smoke stopper, it has to be placed as close as possible to the seat of the fire. This means that it's better to place the smoke stopper in the door of the bedroom in which a fire is burning, rather than in the entry door of the apartment. This is especially true for under ventilated fires. As soon as the bedroom door is opened, a flow path will be formed. The fire will draw in and consume fresh air from the adjacent rooms. A smoke stopper placed at the entry door of the apartment will do next to nothing to stop this. If the smoke stopper is placed in the bedroom door, the effect will be much more beneficial.

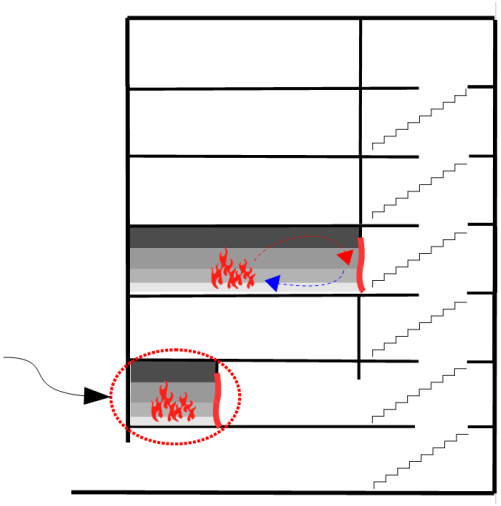

Figure 5 The smoke stopper needs to be placed as close as possible to the fire. *(Drawing: Art Arnalich)*

3 Possibilities

3.1 Limiting the outward flow of smoke

In the scenario of an apartment fire as described above, the smoke flowing into the hallway is an immediate threat to all residents above the fire floor. This outward flow of smoke can be completely stopped by using the smoke stopper. This means that all escape and evacuation routes are still accessible when clearing the building.

In the case of under ventilated fires, it may be opted to put the smoke stopper in place before opening the door. Apartment entry doors almost always open by turning inwards. The exhaust of smoke is avoided all together then.

At ventilated fires, the temperature will be a lot higher. This in turn will cause faster flows. In a traditional interior attack, the crew would have to move in under the smoke that's flowing out. While they're advancing, heat is transferred from the smoke layer onto the firemen. This heat transfer is greater than that of under ventilated fires for two reasons:

1. The difference in temperature between the smoke and the firefighter is larger
2. The speed of the smoke that's flowing out is higher

The smoke stopper will reduce the velocity of exiting smoke to zero. This will greatly limit the heat transfer. Firefighters will be able to operate for a longer time in this environment before getting too hot.

3.2 Limiting the inward flow of oxygen

The smoke stopper will largely cover the door opening, therefor it will also limit the inward flow of oxygen. However the flow will not be totally stopped because the bottom end of the smoke stopper still allows fresh air to enter the compartment. However, this limited flow is far less than that of an open door. Comparing this to anti-ventilation applied by a "door man", we notice that the opening allowing air in is shaped differently. The smoke stopper has a horizontal opening close to the floor that's used completely as an air inlet. A "door man" will leave a vertical opening of about 5 to 10 centimeters wide by 2 meters high. The area below the smoke layer will be used for the inward flow of air. It isn't clear as to which method allows for less air to flow in, but it has to be said that a "door man" will also assist with advancing the hose line. Both systems have their pros and cons.

When looking at the effect of air flowing in, it can be stated that the risk of a ventilation induced flashover is severely limited when the door is the only vent opening. Upon opening a door into an under ventilated fire, ventilation induced flashover can occur within two to four minutes. The smoke stopper will greatly reduce in the inward flow of air. This in turn will seriously delay the fire development. The under ventilated burning regime will remain in effect and fire crews have time to locate and extinguish the fire.

The risk for backdraft will also be gone completely. The so called "gravity current" that's formed upon opening the door, will be hampered by the smoke stopper. The gravity current would normally cause the mixing of smoke and fresh air. When the mixing process is hindered, the flammable mixture needed for a backdraft will not be formed.

3.3 Limiting the return flow of fans

Over the past years, several researchers have done tests to determine the optimal positioning for fans. When a fan is placed in front of a door, air will flow in quicker as the distance to the door is shortened. As soon as the air cone of the fan no longer fully covers the door opening, a return flow will be formed at the top of the door opening. The smoke stopper can counter this. Using the smoke stopper to cover the top end of the door, the return flow is halted and the efficiency of the fan is increased.

Figuur 6 The smoke stopper closes the upper half of the door opening. The backflow caused by the fan is limited. The fan can be placed closer to the door. *(Picture: Michael Reick)*

Research has also shown that the size ratio between inlet and outlet is important. When using a fan, ideally the outlet should be larger than the inlet. Most of the time, the size of the openings is determined by the building. The inlet is usually a door opening. The door area size is about 2 m². The outlet can be a window that has been opened. More often than not, the total area size of windows in a room is rather limited. It will rarely be the case that more than 2 m² of windows can be opened. The smoke stopper can reduce the inlet size of the door to 1 m² and thereby increase the efficiency of positive pressure ventilation.

Finally, the smoke stopper combined with PPV will also better protect the apartment staircase. Figure 3 shows there's still an amount of smoke exiting into the staircase when the interior attack is supported by ventilation. Another disadvantage of this approach is that PPV can accelerate the fire development.

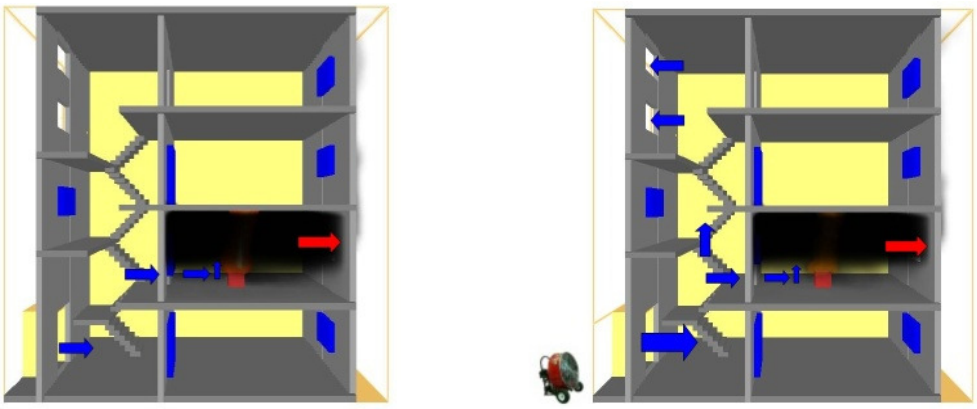

Figure 7 The combination of smoke stopper and PPV fan. The staircase is better protected than in situations where a smoke stopper is not used. *(drawing: Michael Reick)*

By using a smoke stopper, the outward flow of smoke will be stopped. Next to that the impact of the fan on the fire will be limited. A situation where the resident of the fire apartment has left the door open, will have a large amount of smoke in the staircase. The fire service can close off the door opening with a smoke stopper. Next a smoke vent can

be opened. The fan will then clear the staircase of smoke (see Figure 7). Once the smoke has been cleared, the smoke vent can be closed again. An overpressure area will be formed in the staircase that will protect it from any exiting smoke.

3.4 Evaluating fire behavior conditions by assessing the curtain

The smoke stopper is fixed firmly at the top end. At the bottom end the curtain is hanging freely. This means that the curtain is subjected to the influence of the flow path. The curtain can move and by observing that movement, several conclusions can be drawn. There are three different possibilities:

1. The curtain is moving inward.
2. The curtain is hanging still.
3. The curtain is moving outward.

When the curtain is moving inward, it can be concluded that there is a second ventilation opening. The fire is probably venting smoke through a window or a second door into a terrace. The space underneath the smoke stopper is efficiently used to draw in fresh air. The second vent could have a bidirectional flow so the fire will get a lot more air than when only the front door would have been available. It is important to note that a vented fire will have reached a substantial heat release rate.

When the curtain is hanging still, no second opening is available for the fire. This means that the fire is dependent for growth on the air coming from underneath the smoke stopper. Because this is a very small area, the fire itself will remain small. The fire is ventilation controlled in this case. It is possible that the curtain will move slightly from time to time. This is caused by a shifting pressure difference with the outside environment.

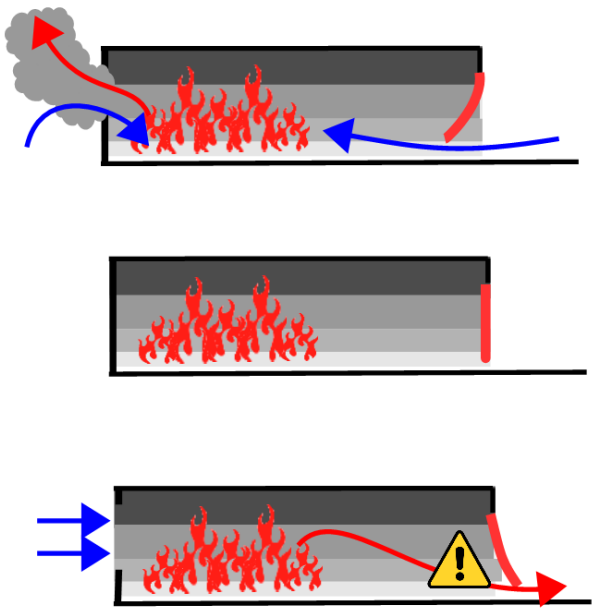

Figure 8 Three possible positions of the curtain give information on the fire in the compartment. *(Drawing: Art Arnalich)*

A dangerous situation has arisen when the curtain is moving outward. The curtain will only move outward when there's a flow into the protected area. Typically there will also be smoke coming from beneath the curtain. In this case there will also be a second ventilation opening. However in this case the wind is causing the second vent to become a full inlet.

Such situation can indicate a wind driven fire. It's important to practice extreme caution here. Another situation in which the curtain is moving outward is that of a fire in a two story apartment. Usually the entry door is located at the bottom floor, but this isn't always the case and sometimes there are even two entry doors. When the fire's on the floor below

the entry door with the smoke stopper, then that door will function as a chimney. This will cause the curtain to move outward.

3.5 Limiting smoke damage

The smoke stopper also limits damage done by smoke to the rooms adjacent to the fire room. The amount of damage caused by smoke is often considerably high on the fire ground. Every surface that has been in contact with smoke has to be cleaned. This is a huge job. Often a lot of objects are beyond salvage and have to be thrown out. Walls have to be cleaned. Next they are treated with a specific product to neutralize the smell. More often than not, the walls have to be repainted.

Figure 9 Fire in a hospital room in Germany. The left picture shows that the hospital room was completely smoke filled. The right picture shows the hallway. In the middle of the picture is the door leading into the fire room. There is no smoke damage in the hallway. The smoke stopper is on the floor at the right end of the picture. *(Photo: Michael Reick)*

All of this causes cleaning costs to rise in rooms where there was no fire. Especially where the smoke has to travel through several rooms before exiting, damage will be enormous. Using the smoke stopper will largely prevent this damage. Figure 9 shows an example of the effects of using a smoke stopper. A hospital room is covered with soot after a fire. However the smoke stopper has prevented any damage being done in the hallway.

4 Disadvantages

Naturally the smoke stopper has its disadvantages. The smoke stopper is placed in a carrier bag. This bag has a certain size. The attack crew already has to carry a lot of equipment with them: SCBA's, thermal imaging camera, hose coils and cassettes, halligan tool, … It may be impossible to bring along an extra bag containing a smoke stopper. Luckily under ventilated fires offer a certain time frame in which to act. Here the fire service has to consider alternative scenario's. If there's an under ventilated fire in a room behind a closed door, then one fireman can go and fetch the smoke stopper. At the same time a fan can be put in place to clear smoke leaking through cracks and pressurize adjacent rooms. Once the smoke stopper is in place, the interior attack can be initiated.

A second disadvantage occurs at ventilated fires. When the fire service is confronted with a fire in growth stage, a smoke layer has been formed. The smoke is flowing toward neighboring compartments. This will cause the smoke layer to drop very slowly and it

means visibility remains intact. The moment a smoke stopper is put in place, the smoke layer will drop more quickly. This will cause visibility to decrease at an accelerated pace.

5 Closing remarks

The smoke stopper is a well-known piece of equipment in Germany. There are over 10.000 currently being used. Prof. Reick has gathered reports of 1400 fire ground interventions in which the smoke stopper has been used. Clearly this means that the smoke stopper is a valuable addition to our fire ground tool box.

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