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The offensive exterior attack: extraordinary?

Perspective for a practical application based on four experimental studies

De Brandweeracademie is onderdeel van het Instituut Fysieke Veiligheid.

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Preface

In the past few years the Brandweeracademie (Fire Service Academy) of the Instituut Fysieke Veiligheid (IFV, Institute for Safety) worked on four major experimental studies, which aimed to find techniques for an effective offensive exterior attack. The four separate reports have very well substantiated how they were conducted and what the results were. However, the extensive reports are not always easy to read.
In this summary report describe clearly what the outcome from the studies is and what practical application it has delivered for the daily practice.

We have learned both from the results as well as the process of researching. Research in this way has been new to the organisation of Dutch Fire Services and to the Brandweeracademie. Gradually we have, for example, measured more parameters. At the start of the first research in 2012, we were only able to measure temperature and make video recordings. In the latest research in 2016 the range of measuring equipment was expanded extensively. Due to the many data collected, it took longer than expected to process all data. We learned from that too.
All experiments were conceived by a team of experts consisting of colleagues from different regions and conducted together with firefighters from the participating regions. Together we learned from designing and doing research and interpreting results. With our Dutch colleagues inspiring discussions developed about the profession of firefighting. Any research was a logical step following the previous. In this process we have discovered that we sometimes think of a particular presumption when thinking about research, which afterwards does not always turn out to be true. The results of this study were therefore surprising and led to an adjustment of the goals we originally set for the offensive exterior attack. There are more crucial factors than the cooling and the place where the attack is made whether or not it will succeed.

The test results are included in the ‘The renewed view on firefighting' and have provided a practical application for the colleagues in the daily practice.
No theoretical scientific study, but a true connection between practice and science, as the Brandweeracademie advocates with all its research! The fire service in the Netherlands has undergone a major development with this research and can now also count internationally to the leading fire brigades that have done real research for and by the fire service. We can be proud of that!

The Brandweeracademie has been able to carry out experimental studies with the Ministry of Security and Justice, the Twente Safety Campus, part of Troned and the safety regions Amsterdam-Amstelland, Brabant-Noord, Brabant-Zuidoost, Groningen, Haaglanden, Midden- en West-Brabant, Noord-Holland Noord, Rotterdam-Rijnmond, Twente, Utrecht, Zaanstreek-Waterland and Zuid-Limburg. I would like to thank everyone for the cooperation in realizing these good researches. I hope that you enjoy reading this report!

Ricardo Weewer,
Professor of Fire Service Science

Content

Introduction

During the tragic fire in a warehouse in De Punt, three colleagues lost their lives in 2008. They became victims of unexpected fire spread. The event in De Punt was the trigger for a thorough reflection on the risks of repressive performance for fires in buildings to a number of firefighters. In this development, the quadrant model for structure firefighting was developed later in collaboration with the firefighters in the field hosted by Netherlands Fire Service and the Brandweeracademie. The model shows the (tactical) choices which were previously not standardized (Brandweeracademie, 2014).

The quadrant model, the first practical elaboration of the fire safety doctrine, supports the choice of firefighting tactics in a building and is a tool for fire operation commanders to make a choice for the most suitable tactic in firefighting (in buildings).

The quadrant model consists of four operational tactics, where the defensive exterior attack and offensive interior attack traditionally are the traditional firefighter tactics. New in this model are the offensive exterior attack and the defensive interior attack. In this publication, research into offensive exterior attack is central.

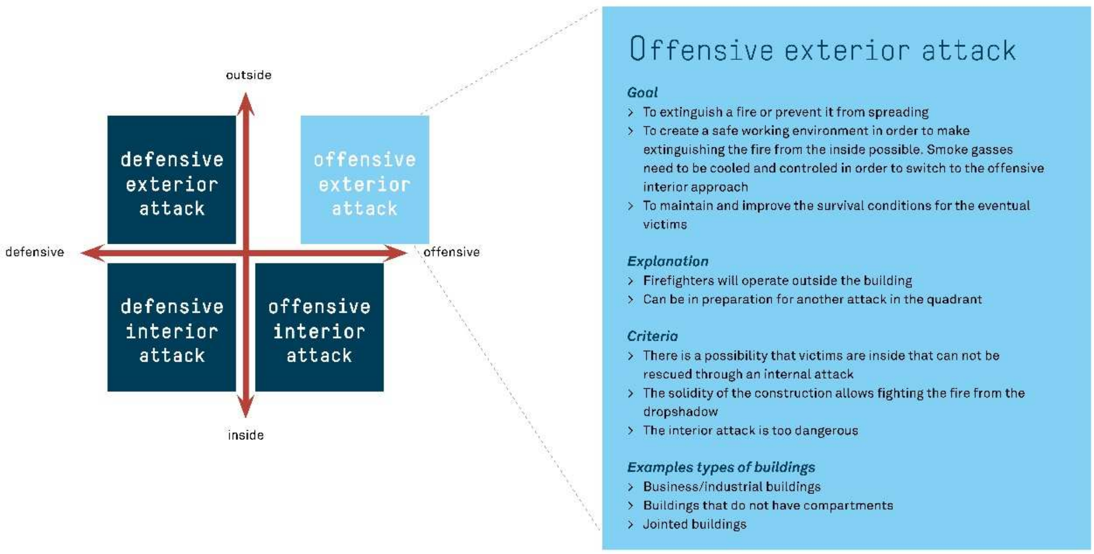

Figure 0.1 The quadrant model and the offensive exterior attack

Offensive exterior attack

The quadrant model does not describe how and with what means to act. In order to provide a useful practical application for the firefighters in the field, the Brandweeracademie together with the Netherlands Fire Service have set up a project called Offensive Exterior Attack (OBI). For this project, a number of full-scale practical experiments have been carried out over a five-year period.

The purpose of the OBI-project is to investigate the usefulness and effectiveness of cold cut system, fog nails and distributor nozzle in a controlled but as realistically as possible context, to investigate their applicability for offensive exterior attack. In addition, high pressure, low pressure, high pressure foam and ventilation have been investigated to determine whether they can also be used for offensive exterior attack. During the experiments, a ventilation-controlled fire has always been the starting point. The focus is on whether or not the objectives of offensive exterior attack can be achieved. These objectives have been investigated in sub-studies in various configurations, with the starting point being that safe entry[1] is not possible because of hot combustible gases in the smoke. However, eventual entry is desirable because of the presence of victims in the building.

The main research question for the entire OBI-project was:

> To what extent can the chosen offensive exterior techniques achieve the intended objectives[2] for an offensive exterior attack at ventilation-controlled fires under several circumstances?

The main question will be answered according to subsidiary questions, these are based on the three objectives of offensive exterior attack.
> To what extent can the selected offensive exterior techniques *extinguish* the *fires*?
> To what extent can the offensive exterior selected techniques create a *safe indoor situation* and be maintained in order to make an offensive interior attack possible?[3]
> To what extent can the *survival conditions* of potential victims be *retained or improved* with the selected offensive exterior techniques?

Sub-studies

The OBI-project is divided into four sub-studies, with all research questions answered in each sub-study. The division into sub-studies was necessary because at the start of the project, hardly any experience was available in carrying out practical experiments. In addition, the results of the previous sub-study were used as input for the following sub-studies.

Offensive exterior techniques have been investigated under different circumstances, distinguishing between building types with associated building materials, a lower or higher fire load, an accessible seat of the fire or a shielded seat of the fire, an expandable or non-expandable seat of the fire and attack directly into the room where the fire was located or indirectly through another room. Finally, the following four sub-studies are carried out for the OBI-project.[4]

> OBI 1: *Field Experiments with techniques for the offensive exterior attack* (May 2012)
An exploratory study into offensive exterior attacks in an industrial environment with a relative low fire load, with direct firefighting attack on the seat of the fire.
> OBI 2/3: *The offensive exterior attack, complete or complex?* (November 2015a)
A study into offensive exterior attacks in a four-room apartment with a high seat of the fire that was not directly accessible.
> OBI 4: *Can the offensive exterior attack be realized?* (February 2016)

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[1] Door management, sufficient cooling power and up to 1 length of insertion depth.
[2] See figure 0.1.
[3] By cooling smoke gases and maintaining the situation after the offensive exterior attack for some time to switch to offensive interior attack.
[4] The research reports of the four sub-studies can be downloaded here on the website of the IFV.

A study into offensive exterior attacks in a small office building with two rooms and a high fire load, either attacking indirectly or directly into the room where the fire was located.

> OBI 5: *Offensive exterior attack: Large building, major worries?* (May 2016)
  A study into attacking in an industrial environment with high fire load and attacking a not directly accessible fire in the fire room.

In the table below the research design of the different experiments is shown. For general information on (the justification of) the research method, see Appendix 1 and the separate sub-reports for specific details.

Table 0.2 Research design four sub-studies OBI-project

		OBI 1	OBI 2/3	OBI 4	OBI 5
Building characteristics	**Building types**	industrial hall	home	office building (small)	industrial hall
	Lay-out building	simple	complex	complex	simple
	Material building	steel with insulation	steel with partial stone walls	steel with partial stone walls	steel with insulation
Fire characteristics	**Potential heat release rate**	9700 MJ	3200 MJ	5800 MJ	21945 MJ
	Seat of the fire accessible	accessible	not accessible	accessible and not accessible	limited accessible
	Seat of the fire expandable	no	no	no	yes
Intervention atributes	**Attacking in**	room where fire is located	outside of room where fire is located	room where fire is located and outside of room where fire is located	room where fire is located
	Final criterion*	smoke gas layer < 150 °C	smoke gas layer < 150 °C of max. 3 x 1 minute attack	smoke gas layer < 150 °C of max. 10 minute attack	smoke gas layer < 150 °C or after max. 10 min. 1 unit 2e unit, again 10 min.[5]
	After reaching final criterion	extinguishing of the fire	extinguishing of the fire	effect on interior attack (opening door)	effect on interior attack (opening door)
	Examined techniques	Cold cut system Fog nail Distributor nozzle High pressure foam High pressure	Cold cut system Fog nail Distributor nozzle High pressure foam High pressure Low pressure Ventilation	Cold cut system Fog nail Distributor nozzle High pressure foam Low pressure Ventilation	Cold cut system Fog nail Distributor nozzle High pressure foam Low pressure

[5] In line with practice, upscaling has been included in the research. The first attack took place with the materials of one engine company. If the goal was not reached after the first ten minutes after the first attack, a second engine company with the same technique was deployed.

Measured quantities		temperature	temperature	temperature radiation oxygen carbon monoxide nitrogen oxide	temperature radiation oxygen carbon monoxide nitrogen oxide

** In experiments has been assumed that creating a safe situation has been achieved if the temperature of the smoke gas layer has decreased below 150 ºC. It is assumed that smoke gas layers at this temperature can no longer result in spontaneous combustion. It should be noted that this value has limitations: known is that temperature alone is not a clear boundary for a safe entry situation. Depending on the composition of the smoke, a colder smoke gas layer can also be flammable at the correct mixing ratio and a sufficiently high ignition energy. A smoke gas layer higher than 150 ºC may be non-combustible in an incorrect mixing ratio.*

Target (group)

After publishing the four sub-studies, it is time to make up the balance. The objective of this fifth publication in the OBI-project is therefore twofold:

> Provide the fire service insight into the practical application regarding offensive exterior attack.

> Describe the extent to which the stated goals of the offensive exterior attack (see figure 0.1) can be achieved using different techniques.

The target group for this overview publication is formed by fire operation commanders, employees involved in professional competence and employees involved in the selection of materials. The practical application can then be shared with firefighters.

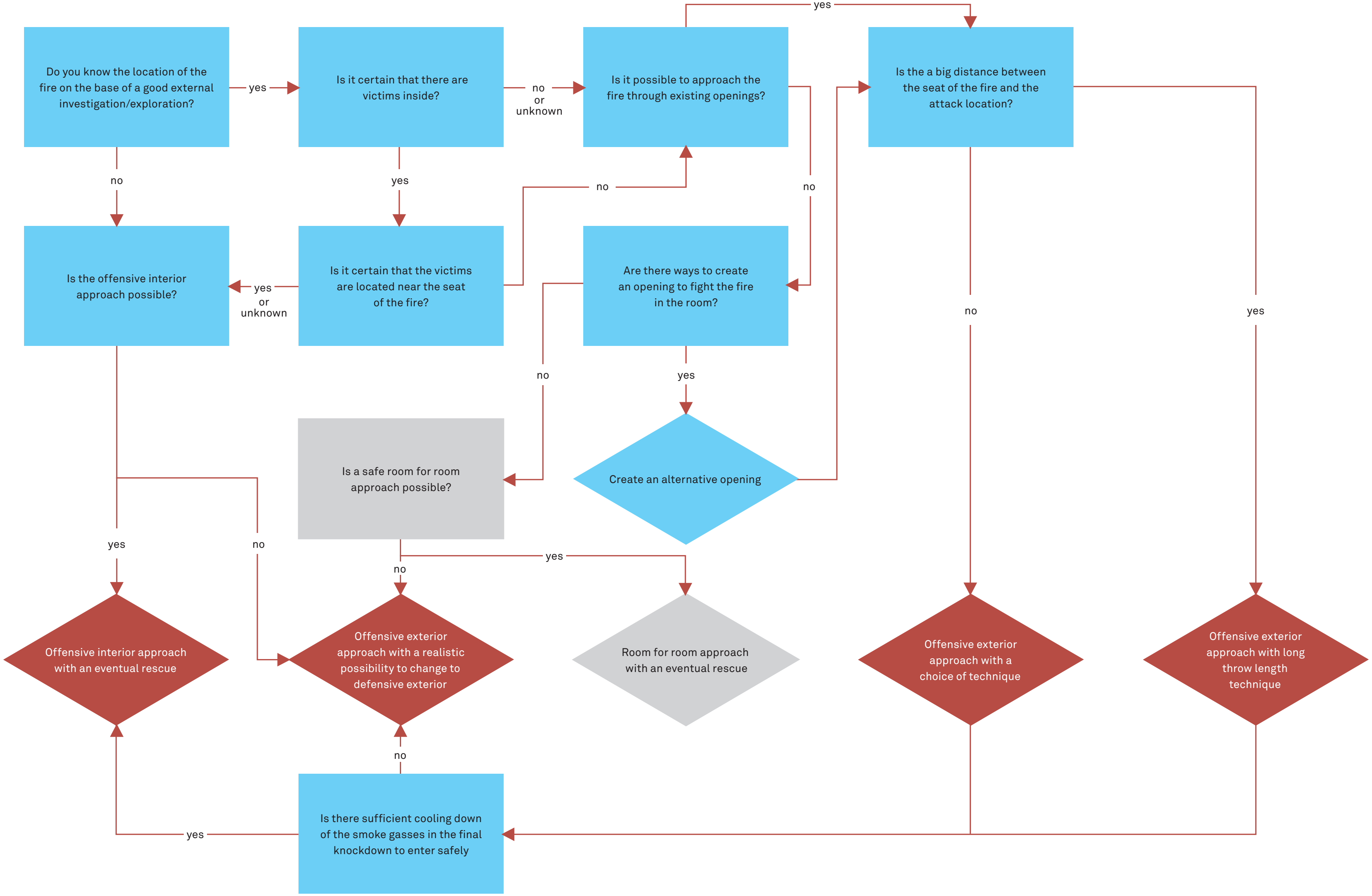
Focus of the study

This publication is based on four extensive studies, including the research design, the results of the techniques and the conclusions. The purpose of this publication is explicitly not to extensively repeat the justification of the methodology and all research results of these sub-studies. This publication focuses on main outlines and overall results. For detailed (justification of) the results of the various studies, reference is made to the corresponding research reports.

1 Recommended perspective for a practical application in the offensive exterior attack

Based on the results from OBI 1, 2/3, 4 and 5 and the knowledge collected from high pressure foam research (Brandweeracademie 2013; 2015b), smoke detectors (Brandweeracademie, 2015c) and practical experiments in Zutphen (2015d), but also based on incident evaluations, a perspective for a practical application has been developed for offensive exterior attack. It is noted that each fire, each building and the details of each situation differ in such a way that one model can never display all possible and correct decisions. Additionally, many things are unclear during a fire, which makes decisions by definition partly based on assumptions. The model is therefore primarily intended as *support* for fire operation commanders when choosing whether or not to apply the offensive exterior attack in structure fires. The model is applicable both to home- and industrial fires, with and without (potential) victims.

The model focuses on a number of questions that can be used by fire operation commanders in choosing whether or not to apply the offensive exterior attack for structure fires. New in this model is the assumes that any structure fire is initially controlled from outside, not only because of safety but also because of speed and effectiveness. This even applies in situations with victims inside.
The model also reflects the circumstances under which an offensive interior attack is preferred over the offensive exterior attack. This is the case when the location of the fire is unknown or if there are certain victims in which it cannot be excluded that they are located near the seat of the fire. In those cases, offensive interior attack is preferred, of course only if there is a possibility for safe entry.
Excluded in the model is when the fire is small and has not yet been expanded that the damage, caused by an offensive exterior attack, is not proportional to the limited seat of the fire. Also see figure 1.1.



The ‘room-for-room-attack’ has to be further elaborated and investigated and is therefore coloured grey in the offensive exterior attack model.

Figure 1.1 Perspective for a practical application of the offensive exterior attack

The following questions in the practical application are asked the fire operation commanders:

1. Do you know where the fire is based on a good exterior exploration?

Offensive exterior attack has been proven to be most effective when attacking directly in the fire room. Therefore, the location of the seat of the fire is an essential part of the exterior exploration, prior to an offensive exterior attack.
If there is no clarity based on the exterior exploration, it must be considered whether a safe offensive interior attack is possible. If so, then the interior attack can still be followed. In general, this will not be possible for large buildings (commercial buildings) unless the fire is discovered immediately and the fire service is instantly alarmed. If that is not the case then there is a predictable outcome. The defensive attack must be applied.
If an offensive interior attack is not possible and the location of the fire is unknown, it is advised to attempt an offensive exterior attack. There may be rooms in the building where there is a survivable situation and potentially victims can be saved. An offensive exterior attack, if safe, can be preferred above an defensive exterior attack in a situation with victims inside, where entry because of fire and smoke is not possible.
The fire will be controlled sooner, this increases the survival rates for victims in areas other than the fire room. Even without victims inside, an offensive exterior attack is advised, as there is a chance that the location of attacking still is the fire room, and in that case an effect can still be gained. However, there is a real chance that the offensive exterior attack has hardly any effect and eventually it has to be switched to defensive exterior. In addition, there is always a possibility if the building is closed and kept closed to keep the fire controlled.

2. Is it certain that victims are inside?

It has been proven that offensive exterior attack can lead to a rapid knockdown or cooling of the smoke gases. On the other hand, adverse effects on victims survival opportunities have been proven in a number of situations.
In the situation where the presence of victims is unknown, it is preferable to attack directly to the fire room for an offensive exterior attack. After all, this results in ‘quickly turning off the engine’ of the fire. In addition, the building is then sooner and safer to enter for fire fighters, which is also important for the situation of potential victims.

3. Is it certain that victims are the near the room of the fire?

Is the victims location unknown, or it is clear that they are located in or in the immediate vicinity of the fire room, then offensive interior attack[6], if safe, is desirable. If there is (relative) certainty that there are victims in the building, and it is sure that they are *not* in the immediate vicinity of the fire room, for example on another floor, then the offensive exterior attack is preferred because of speed and limitation of further fire growth. Of course, every situation is unique. The fire operation commanders should make an integral consideration, a long route of attack or just a location of the victim right next to an exit can lead to other considerations.

4. Can you directly attack in the fire room?

Offensive exterior attacks are effective with almost all techniques when this occurs directly in the fire room. This requires an opening in the outer walls or roof. If there are existing openings or if this can be achieved with the particular technique[7], then this is preferred. It is important to minimize oxygen supply as far as possible in case of under-ventilated fires, thus making the opening as small as possible. If this is not the case then attempting to create an

[6] It is currently unknown what effects an offensive interior attack has on victims survival. This is why is chosen for the offensive interior attack when victims are in the fire room. If a follow-up study shows that offensive interior attack has similar negative effects, this practical application may be adjusted.
[7] For example, create a hole with the grit of the cold cut system or hit the fog nail point through a wall.

alternative opening should be attempted. If this does not work, an offensive exterior attack in the fire room is excluded. The study has shown that an offensive exterior attack outside the fire room in a multi-room building (a complex layout) has hardly any effect, except if there is not more than one room in between and in this room is in line with the adjacent room.

The room-for-room attack?

The current quadrant model offers in the situation that offensive interior attack is not possible, the operational perspectives for defensive interior and defensive exterior. As a matter of fact defensive interior is not the case if the building consists of one fire compartment. Defensive exterior, and thus the predictable outcome for the burning building, is then the alternative according to the current model. However, there is another alternative. During the experiments it has been proven that, despite the fact that there was no effect in the fire room, it was possible to obtain a sufficiently high cooling in the first room attacked. This offers the opportunity to enter the first room after this offensive exterior attack, where necessary the door to the next room can be closed and to start an 'offensive exterior attack' on the second room, etcetera. In this report and for the time being it will be called the room-for-room attack. This method needs to be further elaborated.

5. Is there a big distance between the location of attacking and the seat of the fire?

In case it has become clear that one can perform offensive exterior attack in the fire room, then there is still the question about the distance from the location of attacking to the seat of the fire. The aim is to choose the approaching location so that this distance is as short as possible. Techniques with a large throw length also prove to be effective over a long distance, while other techniques are only effective at small distances.[8] If the best approaching position is chosen, and if you still have a large distance, the technique with a large throw length should be chosen. Hereby the specific characteristics of firefighting technique should be taken into account.

Following this question, one can perform offensive exterior attack with a suitable technique. The offensive exterior attack is performed as long as the knockdown is created and the smoke gases are cooled sufficiently. Then, as long as it is safe, it is still necessary to carry out an offensive interior attack to extinguish the fire and still carry out any rescue. It has been shown that after finishing the offensive exterior attack, over time, the fire flairs up during the experiments, resulting in increasing of the temperature and fire. It is therefore advisable to continue the offensive exterior attack until the offensive interior attack team is ready for use. During the offensive interior attack, a good visibility should be created as soon as possible and in the shortest possible way extinguish the remains of the fire.

[8] The meaning of 'big' and 'small' are relative. One should know the possibilities and limitations of the offensive exterior attack techniques that are available.

2 Results per technique

The second purpose of this overview publication is to describe the extent to which the three goals of offensive exterior attack can be achieved using different techniques. In this chapter, the most important results are shown per attacking technique.

2.1 Cold cut system

2.1.1 Extinguishing the fire

If it is not exactly clear where the seat of the fire is located and how it is accessible, then change the angle of the cold cut system now and then (more towards the ceiling or more straight forward in connection with turbulence).

When using the cold cut system it seems essential that it is used in a straight line towards the seat of the fire. A knockdown with the cold cut system creates 'around the edge', so the seat of the fire is 90 degrees in relation to the approaching angle, turns out almost impossible. The cold cut system has a large throw length.

It is possible to switch under conditions to an interior attack. Enough time is available for this, provided that the team is ready and make their way to the seat of the fire as soon as possible for extinguishing the fire. The experiments have shown that the fire can flare up in a few minutes after finishing the offensive exterior attack. In that case there is a rapid increase of the fire and temperature in that room. It therefore calls for an alert and quick offensive interior attack. In short, after a knockdown entering and extinguishing of the fire is necessary to permanently extinguish glowing remains.

The limited flow rate of a cold cut system is the reason that in case of a large amount of fire load multiple cold cut systems could be deployed. However, it has been found that the use of multiple cold cut systems is not always more effective: sometimes, deploying one cold cut system cools better than two. Interference from the mist nozzle flow plays a role in decreasing the effective range.

2.1.2 Creating safe location indoors

When used directly in the fire room, the cold cut system cools well and relatively quickly (large space within minutes) throughout the whole room. In case of an attack not directly into the fire room, the cold cut system has a cooling effect on the space used, but not on the fire room. If there are no blockages, attacking in a straight line (for example, two rooms after each other with an open connection, such as a door) is initially effective. However, due to the fire flaring up (see above at extinguishing), during the deployment of the cold cut system, the temperature will increase again up to the starting temperature of the attack. In the case of blockages or 90 degrees placed rooms, there is no effect on the cooling other than in the straight section.

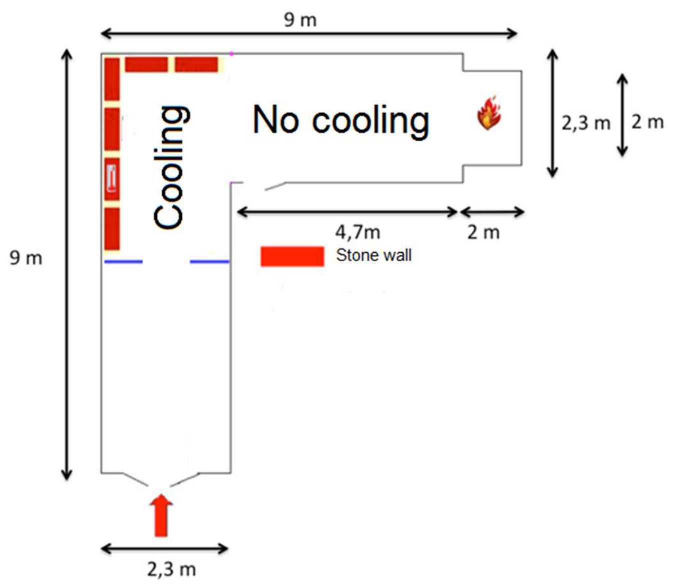


Figure 2.1 Approach cold cut system 90 degrees at the seat of the fire

The cooling of the cold cut system does therefore not work for smoke gases that are around the edge, even with an open connection or a small space. That water fog of the cold cut system may behave like a gas that also travels in a multi-room building (a complex layout) towards the seat of the fire, has been disproven by the study.

2.1.3 Maintain or improve the situation for victims

Due to the use of a cold cut system, turbulence will develop in the smoke gas layer, causing the smoke gases to increase in the room. The smoke gas layer that is initially on the ceiling can thus move to the victim level. This usually results in a deterioration of parameters such as CO, oxygen and nitrogen oxides. In the experiments, a clear increase in radiation has also been observed at the victim level, possibly as a result of the turbulence. However, the temperature decreases at victim level. It calls for further investigation to make a definitive ruling on the effects of the cold cut system on radiation for victims.

In summary

The cold cut system is effective with low water consumption and a large throw length when the room of the fire is accessible and the fire load is in a straight line from the attack location. The large throw length also allows effective attacking in buildings requiring large distances, provided that the above conditions are met.
An offensive exterior attack with a cold cut system in a multi-room building (a complex layout) without accessible seat of the fire is not guaranteed to be successful. The use of a cold cut system does not necessarily lead to better circumstances for present victims. In certain situations, the attack even leads to a deterioration due to the displacement of smoke gases towards the victim.

2.2 Fog nails

2.2.1 Extinguishing the fire

The use of fog nails during offensive exterior attack is effective in the case of extinguishing with a small, well-accessible seat of the fire. In that case, a quick knockdown will be achieved. If it is not possible to hit the seat of the fire directly, fog nails are moderately effective due to the limited throw length. Sometimes, at first, a knockdown is created, but the fire still flares up during the attack. An offensive exterior attack with a fog nail in a multi-room building (a complex layout) without an accessible seat of the fire does not lead to extinguishing. If the attack with fog nails leads to a knockdown, damping down the glowing remains of the fire is necessary.

2.2.2 Creating safe location indoors

Also for the cooling of the smoke gases fog nails are especially effective in a limited and well-accessible seat of the fire. However, the fog nails only have effect in the room of attacking, not in adjacent rooms. The cooling ability is limited. Fog nails are particularly effective in the straight line, more than in a situation with an angle. After the final criterion is achieved, switching to an interior attack is possible. However, this calls for an alert and rapid offensive interior attack, because the fire will flare up after the switch causing a strong rise in temperature and radiation.

2.2.3 Maintain or improve the situation for victims

The use of fog nails does not have a negative effect on the temperature. After a limited increase, a strong lowering of the temperature will soon follow in the room of attacking. In a building with multiple rooms there is only an effect in the room of attacking. However, there is a strong increase in radiation at the time of attacking. This applies both in the fire room and in the adjoining rooms. At the time of attacking, a decrease in oxygen is seen and an increase in CO. An attack of fog nails therefore does not lead to an improvement in the situation for victims.

In summary

Fog nails use little water, but are relatively limited effective because of the limited throw length and ability to cool deep in the building. An offensive exterior attack with fog nails is especially effective at low, accessible fires, or at locations that are hard-to-reach, such as a cavity wall.
An offensive exterior attack with fog nails in a multi-room building (a complex layout) without an accessible seat of the fire seems to be of limited use. The use of fog nails does not lead to an improvement in survival opportunities for victims.

2.3 Distributor nozzle

2.3.1 Extinguishing the fire

An offensive exterior attack with a distributor nozzle leads to a quick knockdown, if the water of the distributor nozzle reaches the seat of the fire. If the seat of the fire is not accessible, for example, because it is in an adjacent room or the distance to the seat of the fire is too big, there is no extinguishing effect. This should take into account the sideways movement of the distributor nozzle. The water is spreading in a disk-shaped motion rather than in a cone shape. This should be taken into account when selecting the attack location. Even when using a distributor nozzle, fires in the glow stage remain and switching to an offensive interior attack is necessary to extinguish the fire.

2.3.2 Creating safe location indoors

In the case of cooling, the distributor nozzle is effective when used in the fire room and with an accessible seat of the fire. In the case of an inaccessible seat of the fire in the fire room, there is a limited cooling. If the distributor nozzle is used in an adjacent room, there is a very limited effect. In a multi-room building (a complex layout) a deployment with a distributor nozzle has a limited effect.

The large droplet size and limited throw length in the longitudinal direction limit the possibilities for cooling. In addition, the water disk can provide a 'block', which can increase the temperature near the seat of the fire.
Once the final criterion has been reached, switching to an interior attack under conditions is possible. However, this calls for an alert and rapid offensive interior attack because the fire will flare up after switching causing a strong rise in temperature and radiation.

2.3.3 Maintain or improve the situation for victims

The use of the distributor nozzle has no negative effect and in some cases even a positive effect on the temperature at the victim level. This is due to the large amount of water that is being inserted, also towards the floor. However, there is a strong increase in radiation at the time of attacking. Due to the turbulence as a result of the attack, the hot smoke gas layer at the ceiling is spread. This worsens the situation for the victim: CO values increase and oxygen on victim level decreases. An attack of the distributor nozzle does therefore not lead to an improvement in the situation for victims.

In summary

The distributor nozzle brings in a large amount of water, where if hitting the seat of the fire is succeeded it can have a big effect. Conditions are that the seat of the fire within reach of 6 meters (the length of the distributor nozzle) and the lateral throw length can be reached. The starting point is therefore to use as close as possible to a seat of the fire, taking into account the distribution of the water with an angle of 90 degrees.
The limited throw length in the longitudinal direction and the large size of the droplet means that the distributor nozzle is not suitable for smoke gas cooling in a large or a multi-room building (complex layout) or in a fire with an unreachable seat of the fire. The attack of the distributor nozzle does not lead to an improvement in survival opportunities for victims.

2.4 High pressure foam

2.4.1 Extinguishing the fire

In the attack with high pressure foam in the fire room where the seat of the fire is directly accessible or shielded, a fast and lasting knockdown will be created during the attack. Even when used in a room adjacent to the fire room and in extension of that, a knockdown can be achieved. This is due to the large throw length and the fact that the foam reaches the floor and flows to the seat of the fire. Special is that the foam does not touch the seat of the fire: it burns up before reaching the seat of the fire. Nevertheless, it initially creates a knockdown. However, after a few minutes, still during the attack, a limited flare up takes place.
In a multi-room building, with an attack location where the seat of the fire is not accessible, there is no extinguishing effect.
In the offensive exterior attack with high pressure foam, remnants of the fire remain in the glow stage, and switching to an offensive interior attack to extinguish the last residues is necessary.

2.4.2 Creating safe location indoors

Regarding cooling, high pressure foam is also effective when used in the fire room and with an accessible seat of the fire. In the case of a non-accessible seat of the fire and attacking in an adjoining room, cooling takes place, but not till the limit of 150 ºC.
In a more complex multi-room building, offensive exterior attack has little or no effect on the seat of the fire. It therefore seems that, because of the throw length and pressure, high pressure foam is more effective in a large room.

After the temperature in the smoke gas layer has reached below 150 ºC , switching to an interior attack, under conditions, is safe and therefore possible. Whether and when a flare up takes place, after opening the door, depends on the extent to which the seat of the fire was well-reachable. At a well-accessible seat of the fire, no flare up has been seen in the experiments, while at a less accessible seat of the fire a flare up takes place after a couple of minutes when opening the door. On that account it is also important to perform an alert and rapid offensive interior attack after ending an offensive exterior attack.

2.4.3 Maintain or improve the situation for victims

In the case of high pressure foam, the temperature remains stable or, after a limited increase, it rapidly decreases significantly in the room of attack.
Although, there is an increase in radiation and CO at victim level, presumably due to the disruption of the smoke gas layer through the attack.
During the attacks with high pressure foam it was observed that after a few minutes a thick layer of foam (20-30 cm) was formed on the floor. What the possible effects of this are on victims laying on the floor is unknown.

In summary

With high pressure foam an effective offensive exterior attack can be realized, especially when the seat of the fire is well accessible with the foam. Due to the large throw length, an offensive exterior attack with high pressure foam in a large room is possible. The starting point is therefore to enable the seat of the fire to be hit while attacking.
The use of high pressure foam does not lead to an improvement in survival opportunities for victims.

2.5 Low pressure

2.5.1 Extinguishing the fire

With the low pressure attack in the fire room, a fast and lasting knockdown follows in an accessible as well as a shielded seat of the fire. Even when attacked in a room adjacent to the fire room and in extension, a knockdown is created. Low pressure created a lasting knockdown in the above-mentioned situation, not only the fastest but also the only one with a remaining knockdown. In a multi-room building, with an attack location where the seat of the fire is not accessible, there is no extinguishing effect.
Even in the low-pressure offensive exterior attack, there are fires left in the glow stage and switching to an offensive interior attack to complete the last remains is necessary.

2.5.2 Creating safe location indoors

Low pressure cooling during offensive exterior attack gives good results. This applies both in a small room with an accessible seat of the fire, as well as in attacks over a larger distance with a shielded seat of the fire. However, the effect decreases as the fire is further removed from the attack location and the complexity of the building increases.
It seems that low pressure due to the throw length and pressure have the most effect in a large room. Cooling around the edge in a small room is difficult with low pressure.
After the final criterion has been reached, switching to an interior attack under conditions is safe and therefore possible. Whether and when a flare up after opening the door takes place will depend on the extent to which the fire can be reached. In the case of an well accessible seat of the fire, no flare up has been seen in the experiments, while a less easily accessible seat of the fire a flare up takes place after a couple of minutes when opening the door.

As soon as the flare up takes place, temperature and radiation rise rapidly. Therefore, at low pressures, an urgent and quick offensive interior attack is necessary after the offensive exterior attack has been ended.

2.5.3 Maintain or improve the situation for victims

The low pressure attack has a positive effect on the temperature and oxygen level at victim level. The temperature decreases rapidly and oxygen increases in the room of attacking. However, there is a clear increase in radiation and CO at victim level.

In summary

With low pressure, effective offensive exterior attack can be performed, both in the case of extinguishing and cooling, in large or smaller rooms, with an accessible or shielded fire place. The use of low pressure does not lead to an improvement in survivability opportunities for victims.

2.6 Ventilation

2.6.1 Extinguishing the fire

As expected, ventilation does in none of the cases lead to extinguishing. It rather leads to intensification of the fire.

2.6.2 Creating safe location indoors

Through ventilation, the temperature increases rather than decreases in the fire room. However, in the rest of the rooms there is a clear cooling in the conditions tested. In a multi-room building, ventilation of all the techniques studied has reached the greatest cooling in areas other than the fire room. The effect after ending an offensive exterior attack has not been measured because the tests have been prematurely ended due to a too high temperature in the fire room with the construction used.

2.6.3 Maintain or improve the situation for victims

The attack with ventilation has an obvious positive effect on the parameters for the survivability at the victim level. It involves both temperature and parameters such as CO, oxygen and nitrogen oxides. As far as radiation is concerned, the image is varied and depends on the victim's location. In the vicinity of the fire, despite the intensification of the fire, the attack may lead to a limited improvement if the victim is in the ventilation path.

In summary

With ventilation an effective offensive exterior attack cannot be achieved in the context of extinguishing. As a result of ventilation, the seat of the fire increases resulting in the rise of temperature in that fire room. In a multi-room building, ventilation outside the fire room has the effect of improving the situation for the victim, provided that it is in the ventilation path between doorway and seat of the fire.

3 Conclusions

In this chapter, the overall findings of OBI 1, 2/3, 4 and 5 on the offensive exterior attack are based on the three goals of this attack according to the quadrant model and research questions. The conclusions are based on the results of the experiments with the techniques mentioned in this report, namely cold cut system, fog nails, distributor nozzle, high pressure foam, high pressure, low pressure and ventilation.

Objective 1: Extinguishing fire and/or prevent fire spread

When attacked externally in the fire room where the seat of the fire can be reached directly, an offensive exterior attack is generally well able to achieve a knockdown. In larger fire rooms with a seat of the fire in a distance from the attack location, a large throw length is especially important. If a knockdown is reached during the offensive exterior attack, it remains necessary to enter the building afterwards to extinguish the fire.
If the fire room itself cannot be attacked from the outside but exclusively in an adjacent room, the effectiveness of an offensive exterior attack to realize a knockdown is limited. The only chance of a knockdown is the use of the low pressure technique or high pressure foam, the other techniques are not effective. In an attack in a room that is further removed from the fire room, an offensive interior attack is not effective in achieving a knockdown.

Objective 2: Create a safe work environment to allow an interior attack

If a direct attack in the fire room is possible, offensive exterior attack in general is effective in cooling the smoke gases in that room to below 150 ºC. This does not apply to rooms of limited size. If both the room and the distance between the attack location and the seat of the fire are large, only a large throw length technique is effective to cool the entire room.
When attacked in the adjoining room, only low pressure is able to bring the smoke gases in the fire room below 150 ºC. All the techniques studied achieve enough cooling in the adjacent room of attacking.

In first instance a safe entry situation should be created. It is also essential that the situation *remains* safe for a while, so that extinguishing as well as post exploration are safe and therefore possible. Therefore, it has been investigated what happens after discontinuing the offensive exterior attack, in order to switch to offensive interior attack. It has been proven that depending on the size of the building and the extent to which the knockdown was created, there is generally enough time left to switch to offensive interior attack. However, a flare up usually takes place. That moment varies between one and three minutes, but if a flare up takes place, it leads to a rapid increase of fire and temperature.

It can be concluded that the technique is less important than the attack location and the offensive exterior attack can only be performed if small openings can be made (the oxygen supply must be limited).

Objective 3: maintain or improve survival conditions of victims

When an offensive exterior attack is deployed, a (temporary) deterioration of the parameters for the survivability is observed in all the techniques investigated. The extent to which this takes place varies per technique and situation. If the situation for the victim deteriorates, this usually is the cause of a strong increase in radiation and possibly carbon monoxide at victim level that is beyond limits for survival. A possible explanation for this is the turbulence that results from the attack of the offensive exterior attack, so that smoke gases and steam move from the ceiling to the victim's location.
Because it is not known whether an offensive interior attack leads to comparable deterioration or improvements for victims, it is unclear whether it is better for the victim to perform an offensive interior attack rather than offensive exterior attack. Alternative methods (such as rescue without bringing in water) or attacking with combinations of techniques have not been investigated.
What has been shown in the study is that *no* interference eventually leads to even worse parameters[9] for survival for victims.

Remaining conclusions offensive exterior attack

In addition to answering the three objectives, the various OBI studies have provided the following additional information.

Practical workability access offensive exterior attack

The offensive exterior attack is especially effective when attacking in the fire room. After the seat of the fire is located, the attack location should be as close as possible to the seat of the fire. A single technique, the cold cut system, is independently able to provide access. Other techniques require access. For that, the fire service needs equipment to provide rapid access to offensive exterior attack in various building materials. In fact, opening doors just gives an increase in the heat release rate and must therefore be avoided.

Safe situation after offensive exterior attack cannot be observed

In the research, there were plenty of (thermal imaging) cameras and measuring equipment available to measure the temperature and composition of the smoke gases among other things. This could provide an indication of whether the offensive exterior attack was successful and could be switched to an offensive interior attack. Hereby, it is noted that in the daily firefighting practice these resources (Vierhout, 2015) are pretty much unavailable, which makes the desirable moment of switching difficult. In the experiments, it has occurred a few times that the view on the outside of the building did not give any indication of a dangerous situation. There was hardly any smoke or other B-SAHF signs. However, the meters indicated that within the room the concentration of the explosive carbon monoxide (250,000 ppm CO) was well above the lower explosion limit of 110,000 ppm CO. There was also sufficient temperature available, while the oxygen content dropped to almost 0 percent. In such a situation there is a real chance of explosive smoke gas combustion, while the current equipment of the fire service are not suitable for recognizing this risk.

Assumptions about victim survivability

A common assumption within the fire service is that if the fire service can no longer enter the building due to fire or smoke, it is now also a not survivable situation for victims. Both the

[9] It should be noted that exceeding the survivability limit of one of the parameters is just as bad as exceeding more than one parameter. The same goes for a larger exceeding than the survivability limit.

OBI-experiments as well as other recent research conducted by the Brandweeracademie (2015d) have shown that the survival opportunities for victims in certain situations are greater than thought. It turned out that in the adjoining room of the OBI 5 industrial building, the victim appeared to be in a survivable situation despite the opened intermediate door throughout the experiment. This applies both to offensive exterior attack as well to zero measurements that have not been applied.

Improve the possibilities for a good impression of the situation inside during the exterior exploration and during the attack

The fire service is currently depends on visible external signals at exterior exploration, such as smoke and flames through outer wall openings. The thermal imaging camera is hardly suitable for this because the camera cannot look through the outer walls into the building. Futhermore, research has proven that as the fire growth continues, the thermal conduction of the outer walls have developed in a way that the location cannot be determined from the outside (Vierhout, 2015).

The importance of knowing the location of the seat of the fire beforehand to make an effective attack is great, considering the results of the OBI research. In addition, knowledge of the location of the victims is also necessary, which calls for additional possibilities on the current equipment. During the study (OBI 4 and 5), the time of switching was determined based on measuring equipment and cameras. For a fire operation commander, it is hardly possible with the current limited imaging equipment to determine the right time for switching safely from offensive exterior to offensive interior. This involves determining a knockdown, the temperature of the smokes gas layer and the presence of combustible gases.[10] Perhaps products can be developed to support the fire service. For example, a (thermal imaging) camera that makes it able to look into the next room like through an endoscope or a device that composition of the smoke gases and temperature remote controlled or not.

Develop opportunities to create outer wall openings with limited oxygen supply

To perform an offensive exterior attack, an outer wall opening is necessary. The cold cut system and fog nails have features to provide access, but for other techniques, opening is required. Currently, existing openings, such as windows or doors, are used for this purpose. Because openings at suitable locations (close to the seat of the fire) are not always available or because, for example, breaking the window leads to excessive oxygen supply, it is desirable that the fire service has the equipment for rapid and limited access for an offensive exterior attack in various building materials.

[10] In the OBI study it is seen several times that the image on the outside of the building did not give any indication of a dangerous situation. There was hardly any smoke or other B-SAHF signs. However, the meters indicated that within the room the concentration of the explosive carbon monoxide (250,000 ppm CO) was well above the lower explosion limit of 110,000 ppm CO. Also, there was sufficient temperature, while the oxygen content dropped to almost 0 percent. In such a situation there is a real chance of an explosive smoke gas ignition at entry.

Consider adaptation and further development of the quadrant model

One of the objectives of offensive exterior attack in the quadrant model is maintaining or improving survival conditions of potential victims. The studies have looked at effects of offensive exterior attack on survivability parameters for victims. This has proven that the effort in many cases has a negative effect on these parameters. It is therefore recommended to adjust the objectives (for the time being) to the survivability of the victim, until follow-up methods and techniques prove to maintain or improve survival conditions for potential victims.

In the current version of the quadrant model, the offensive exterior attack indicates that it is mainly used for business buildings and buildings without compartmentalization. Based on the practical application as described in Chapter 1, the offensive exterior attack is advised in first place to do 'standard, unless', including fires in the home.

Based on the current quadrant model in a multi-room building (complex layout) and no safe situation for entry, defensive exterior is the only alternative besides offensive exterior. The research has proven that another method, the room-for-room attack mentioned in the model may be effective and safe in these situations. For this, a further elaboration of this method, and research into its effectiveness and safety, is necessary.

Investigate the effects of firefighting on victims survival

This OBI study has proven that, with the techniques investigated, the situation of victims has worsened in the configurations investigated. It is unknown what the effects of the most used quadrant and the alternative, namely offensive interior, are on victims. It is desirable to investigate and, where necessary, revise perspectives for action.

In the case of victims indoors, alternative methods could also be investigated. For instance rescuing without the use of water, or combinations of techniques such as the use of ventilation with offensive exterior techniques.

It has been shown that the radiation increases in particular as a result of the attack. This affects both victims and firefighters present. Further research into the role of radiation is therefore desirable.

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Appendix 1
Research method

In this annex, the research methodology used in the four OBI-studies is briefly summarized. For full justification, we refer to the individual research reports.[11]

Justification chosen research method

The offensive exterior attack is a relatively new attack tactic within the fire service. There are no proven techniques available for this attack, or the effect is insufficiently known. Internationally, there has been research on a particular technique, but a comparison under the same test circumstances of different techniques is not available. Organisation of Dutch Fire Services and the Brandweeracademie believe that the application of tactics and techniques should be based as much as possible on facts, most preferably obtained reliably from standardized circumstances. This is why the offensive exterior attack (OBI) project has chosen a series of full-scale practical experiments. These include all kinds of variations as they take place in daily firefighting practice. Hereby choices were made about which variations were investigated in coordination with the expert group. The advantage of the chosen research method (practical experiments) is that it is closely linked to the fire service practice. On the other hand, it is possible to collect data with measuring equipment under controlled and safe conditions. Basically, because of the variation in fire development, each test with each technique has been performed multiple times under the same conditions, where possible.

Building characteristics

Regarding the building type, the presumption was that offensive exterior attack are often used for an industrial environment, due to the risks of a large fire load and a large building. For homes, firefighters primarily learn offensive interior attack. However, during the study, the offensive exterior attack might also be useful for homes: not so much because entry into a residential fire is excluded, but because performing an offensive exterior attack prior to an offensive interior attack could be of added value for effectiveness and security. Therefore, in OBI 2/3, a home has also been included in the research.

For OBI 1 and OBI 5 an industrial hall has been used, for OBI 2/3 and OBI 4 linked containers.

[11] The four research reports can be downloaded here on the website of the Institute for Safety.

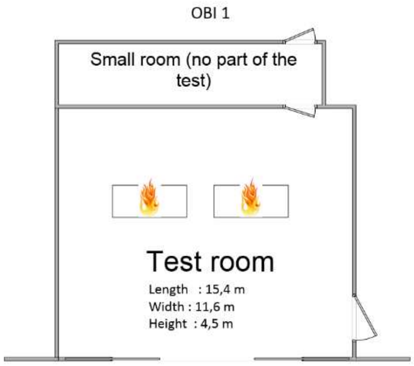

Figure B1.1 Design plan OBI 1

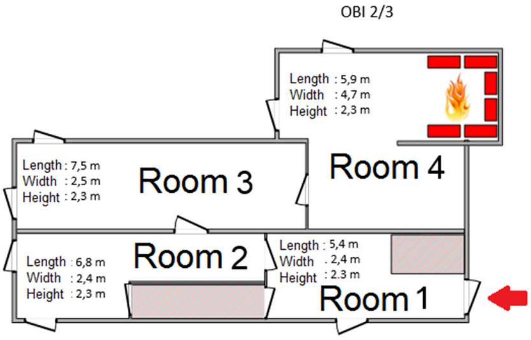

Figure B1.2 Design plan OBI 2/3

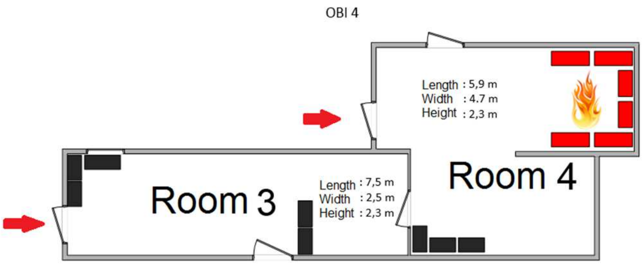

Figure B1.3 Design plan OBI 4

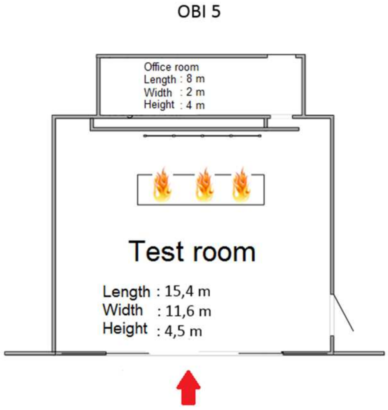

Figure B1.4 Design plan OBI 5

Test have been performed in buildings with different materials, namely insulated steel, non-insulated steel and steel with a partly stone wall. Variation has been applied in both material, the fire load and the seat of the fire. In OBI 1 and 4, the seat of the fire could be reached in a straight line from the attack location. In other sub-studies, there was a shielded fire, due to the presence of obstacles (OBI 5) or walls (OBI 2/3 and 4). In the base, the tests were carried out with a non-expandable fire load: the fire load was located together, the fire load was completely lit and there was no other combustible material in the building. An exception to this is the last sub-study (OBI 5), whereby some chipboard sheets could be exposed to heat radiation.

Figure B1.5 Upper view of the industrial hall

Figure B1.6 Side view of the home/small office

Fire characteristics

All OBI studies involved a ventilation-controlled fire. Only at OBI 5 the fire could expand.

> For OBI 1, the fire load consisted of 32 pallets 121 cm x 102 cm x 12 cm divided into four stacks with a potential heat release rate (HRR) of 9700 MJ.
> For OBI 2/3, the fire load consisted of a stack of nine pallets of 121 cm x 102 cm x 12 cm, one foam mattress (dimension 100 cm x 100 cm x 21 cm) and three chipboard sheets (size 120 cm x 100 cm x 1.2 cm). This amounts to a potential heat release rate of 3200 MJ.
> For OBI 4, the fire load consisted of a stack of nine pallets (about 180 kg of pine wood), 107 kg of chipboard sheets, 9 kg of foam and 4 kg of triplex sheets. This amounts to a total potential heat release rate of approximately 5800 MJ.
> For OBI 5, the fire load consisted of three stacks. Each stack was made of a pallet, then a chipboard sheet (122 cm x 122 cm and 18 mm thick), then 12 pallets and a chipboard sheet on top of it. In total, the primary fire load consisted of approximately 874 kg of pine wood and 107 kg of chipboard. The fire load configuration was such that the fire could expand/pyrolysis could occur. To this end, three pallets were placed on the side at a distance of approximately one and a half meters opposite to the stacks against the wall, with a chipboard sheet on it. This fire load consisted of about 67 kg of pine wood and about 107 kg of chipboard. The potential fire power of the total heat release rate (in the container and against the wall) consisted of approximately 21,945 MJ.

Figure B1.7 Fire load OBI 1

Figure B1.8 Fire load OBI 2/3

Figure B1.9 Fire load OBI 4

Figure B1.10 Fire load OBI 5

Intervention attributes

The choices for the techniques investigated are based on latest insights, which adds techniques (low pressure and ventilation from OBI 2) as well as some techniques for certain scenarios are inappropriate or illogical. For example, ventilation in OBI 5 has not been investigated because the common belief is that ventilation in fires in large-scale buildings is risky. Another technique that has not been further investigated during the progress of the sub-studies is high pressure (HD). HD has been partially investigated in OBI 1 and OBI 2/3 as offensive exterior attack technology. However, quite quickly in the process it has been concluded that, based on the latest insights, low pressure is always preferred over high pressure due to throw length in large buildings and throughput rates in general. HD has not been investigated in the further process. [12]

12 Given the limited scope and capabilities of data registration in OBI 1 and OBI 2/3, it is decided not to make an overall analysis for HD. For reliable statements, there are insufficient data. However, Appendix 1 shows the results for HD from the two OBI projects mentioned above.

The attack techniques have been carried out by firefighters from the participating regions who have been educated and trained for the application of the relevant technique. The method used is according to the latest insights and working instructions in the participating region. With OBI 1 and OBI 2/3, the attacks with the relevant technique have been repeated five times to minimize the coincidence factor in the measurements and observations. In both experiments, the spread in the individual attacks was so small, that it was chosen for OBI 4 and five to bring it back to two attacks.
A lance or branch pipe was used per attack, with the exception of the attack with fog nails in the OBI 1 and OBI 5 sub-studies.

Table B1.11 Frequencies techniques per attack

Number of used lances or branch pipes per attack				
	OBI 1	OBI 2/3	OBI 4	OBI 5
Cold cut system	1	1	1	1
Fog nails	2	1	1	2 + 2 (after 10 min)
Distributor nozzle	1	1	1	1 + 1 (after 10 min)
High pressure foam	1	1	1	1
Low pressure	1	1	1	2
Ventilation	Not relevant	1	1	Not relevant

Various test protocols have been used for the various experiments. These test protocols for the start of the attack have been established with experts from the fire service field.

> OBI 1: When the starting temperature (430 ºC) was reached on the reference thermo couple, the attack was started.
> OBI 2/3: after the fire was ignited and the temperature in the fire room remained constant (targeting 550 ºC) and the smoke gas layer had a sufficient thickness and compaction and the temperature in room 1 was as high as possible, the first attack was started.
> OBI 4: After the fire was ignited and the temperature in the fire room remained constant (targeting 550 ºC) and the smoke gas layer had a sufficient thickness and compaction, the attack was started.
> OBI 5: Started with an attack when a temperature of at least 400 ºC was reached on the reference thermo couple and a smoke gas layer with sufficient thickness and compaction.

In all cases, the final criterion was that the temperature was below 150 ºC on the reference thermo couple. In addition, OBI 4 and 5 also investigated what the effect was of opening a door after the offensive exterior attack. This was done to investigate the effect of opening a door when switching to an offensive interior attack. Here the side door opened for 5 minutes. After reaching the 5 minutes, the experiment was ended.

After each attack, the room was reconditioned. The following actions were carried out, namely:

- Removing the fire remains from the fire room
- Removing the extinguisher from the rooms
- Cooling the walls and air until all thermos couples indicate a temperature below 100 °C.

Measured quantities

In OBI 1 only thermo couples was available for measuring the temperature and the visual image was recorded with regular cameras. In addition to regular cameras, (thermal imaging) cameras were also available since OBI 2/3. Since OBI 4 meters were available for radiation, oxygen (O_2), carbon monoxide (CO) and nitrogen oxides (NO_X). These parameters were necessary for the question of survival and were measured at victim level of 50 cm.
Temperature was measured just below the ceiling (OBI 1, 2/3, 4 and 5), at 1.80 meter (OBI 1 and 5) and at victim height of 50 cm (OBI 2/3, 4 and 5).

Focus of the study

The research results should be considered within the limits of the research. The results only apply to the test runs and scenarios tested. Other practices or scenarios may lead to other conclusions.
For the experiments, only the techniques and methods used in the Netherlands, selected in advance by the expert group, were investigated: cold cut system (CC), distributor nozzle (NK), fog nails (FN), high pressure foam (DLS) and low pressure (LD). In addition, high pressure and ventilation have also been investigated.

The studies has measured the parameters of temperature (°C), radiation, carbon monoxide (CO), oxygen (O_2) and nitrogen oxides (NO_X). The water consumption and the visual image inside are also registered. Other parameters such as air humidity, composition of smoke gases, inertisation of smoke gases and the amount of wood actually burned have not been measured.

Although in the various sub-studies, all kinds of variations in building, fire load, attacking in the fire room or other room, et cetera have been investigated, many other variations have not been investigated. The starting point is that, through the variations investigated, a general picture can be sketched with a general practical application as a result. That does not mean that in all fires the techniques have the described effects. Also, one of the most commonly used methods of attacking has been investigated by investigative offensive interior attack technique. In addition, the materials with technical specifications currently used in the region concerned were used. Other attacks, materials (for example, other branch pipes, pressures or foaming equipment), and other scenarios may lead to other conclusions.
In experiments has been assumed that creating a safe situation has been achieved if the temperature of the smoke gas layer has decreased below 150 °C. It is assumed that smoke gas layers at this temperature can no longer result in spontaneous combustion. It should be noted that this value has limitations: known is that temperature alone is not a clear boundary for a safe entry situation. Depending on the composition of the smoke, a colder smoke gas layer can also be flammable at the correct mixing ratio and a sufficiently high ignition energy.
A smoke gas layer higher than 150 °C may be non-combustible in an incorrect mixing ratio.

Finally, in the OBI 2/3 subproject, a literature review was carried out in 2013. In the following years, the practical experiments were performed, with no literature review being carried out again. Relevant literature published after 2013 is therefore not included in the research.

Appendix 2
Results high pressure

The most frequent technique for an offensive interior attack at present is the use of high pressure. It was therefore the obvious choice to test the offensive interior attack with high pressure too. This has been done in the first two OBI-experiments (OBI 1 and OBI 2/3).
On the basis of evolving knowledge and the outcome of several national and international studies it appears that high pressure is in these situations, because of the low throughput, not preferred above low pressure. Therefore it has been decided that in future the OBI-project will only use low pressure in the tests on the offensive interior attack. The results of the OBI1 and 2/3 are summarized below. Please notice that the results are based on a limited number of experiments.

Extinguish the fire

A quick knockdown is realized using high pressure in a fire room with a limited fire load. It has not been investigated if the knockdown effect remains. There is limited effect on the fire when the attack is in the room next to the fire room or in a complex building. Fires in the glowing stage remain using the offensive exterior attack with high pressure. Switching to the offensive interior attack remains a necessity.

Creating a safe situation indoors

The results of using an offensive exterior attack for a limited seat of fire, directly in the fire room are satisfactory, but less effective than using other techniques for the offensive exterior attack. It should be noticed that using of pulsation leads to an increase in temperature every time when the branch pipe is closed. The structural effect on cooling is therefore limited.
The continuous opening of the branch pipe in an offensive exterior attack is therefore more effective for cooling the smoke gases. The use of the pulsing on adjacent spaces results in a limited cooling in the studied application.[13]

[13] On the basis of these results the Brandweeracademie has decided to research ways for effective cooling of smoke gases in an offensive interior attack.