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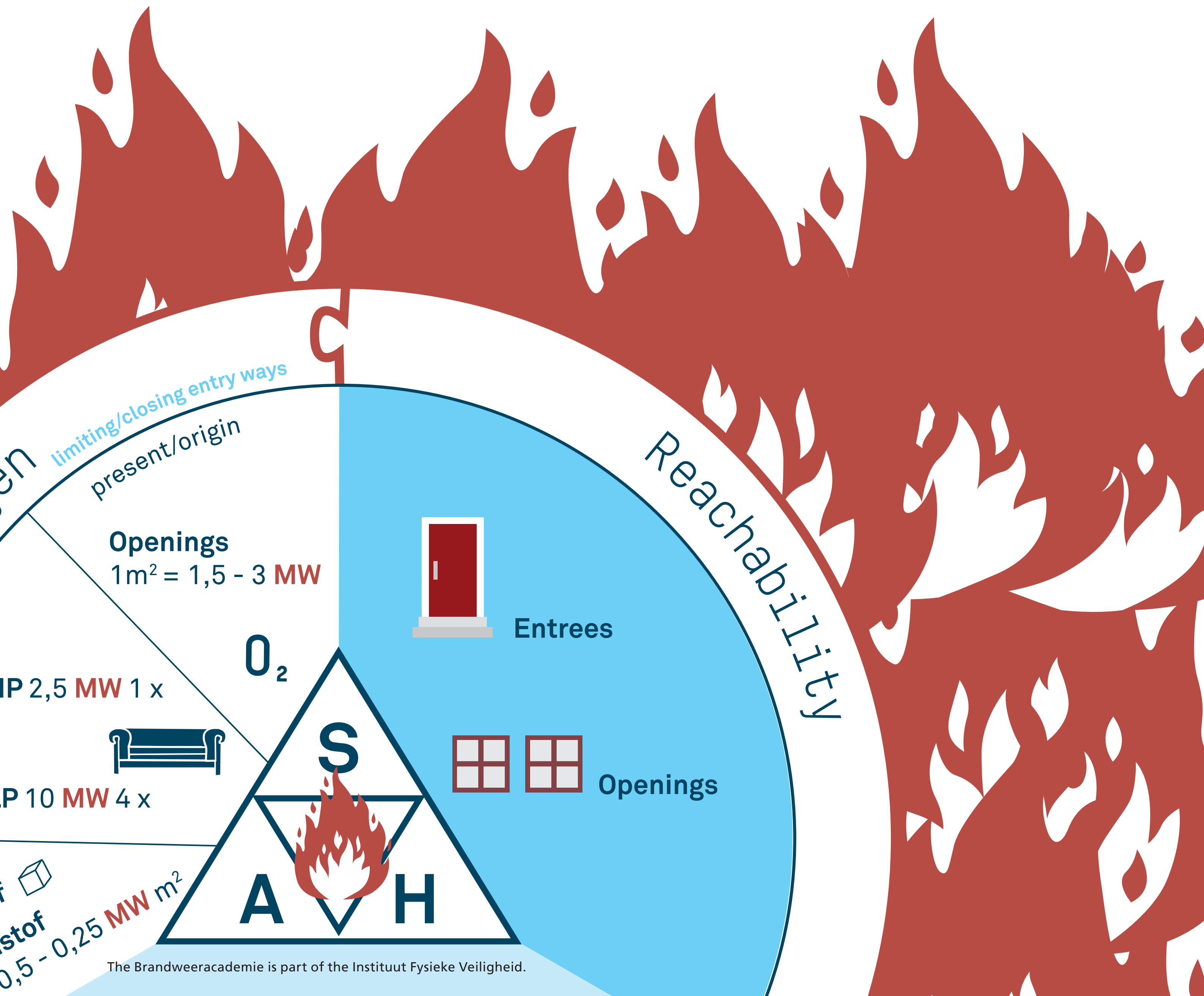
The Renewed View on Firefighting

An evidence-based approach



The Brandweeracademie is part of the Instituut Fysieke Veiligheid.

Instituut Fysieke Veiligheid
Brandweeracademie
PO box 7010
6801 HA Arnhem
The Netherlands
www.ifv.nl
info@ifv.nl
+31 26 355 24 00

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Preface

In my inaugural speech 'The Red Crown Jewels' (Weewer, 2015) I introduced a first version of what I called the 'Theory of the Predictable Outcome' at that time. The theory was based on observations during experiments in Zutphen, the Netherlands (Brandweeracademie, 2015a) and on the initial results of the investigation into the offensive exterior attack (OEA) (Brandweeracademie, 2012). I presented the theory as a possible new standard and paradigm for fighting structure fires. The name of the theory of the predictable outcome was inspired by fires, particularly by those in commercial buildings and larger residential buildings, of which the outcome can be more or less predicted, in both the preventive and suppressive practice. The original name of the theory of predictable outcome has now been abandoned because it was interpreted as a synonym for a burn down scenario. Even though this can be what happens with larger buildings that are on fire, it is does not always happen, and definitely not with smaller buildings such as homes. Incidentally, the theory can also be used to predict at what moment the fire can be extinguished. We changed the name to 'The Renewed View on Firefighting'. In fact, we are revamping a number of old principles and are tightening them up, resulting in practical basic principles for safe and effective firefighting. For now, these basic principles are called 'The Renewed View on Firefighting', but once we get used to them, they will simply be known as the basic principles for fighting structure fires.

In the period following my inaugural speech, a number of investigations have been concluded, among which were an investigation into situational command and control (Brandweeracademie, 2015b), and the final report of the OEA investigations which included a practical perspective for action aimed at supporting the choice whether or not to execute an offensive exterior attack in structure fires (Brandweeracademie, 2017). The results of these investigations and the perspective for action from the final OEA report form the foundation for the renewed view. The foundation is complemented by the principles from command and control (human factor), the fire triangle, the investigative results of Underwriters Laboratories and the rules of thumb for the heat release rate and cooling capacity.

A study group worked with experts from the fire service to create a better insight into the theory. In the context of this insight, the theory of firefighting has been simplified, aimed at its application in actual practice. This need for simplification was dictated by the field. It was, for instance, complicated to apply the (BE)SAHF model in practice. In working together, we succeeded in simplifying the model. We also have worked on rules of thumb for the fire's heat release rate and the subsequent cooling capacity needed. While working on this, we gained the understanding that the majority of the theories on fires and firefighting are more or less known. The knowledge on how to apply the theory in practice is, however, rather less well developed. In recent years, knowledge development of fire and fire behaviour has been discussed in depth, which made it seem like firefighting had become more complicated. Real-life examples show, however, that we do not always apply our knowledge in actual practice, possibly because we often act on (limited) experience and because we do not take the time to think, or both.

In the past year, the renewed view on firefighting was shared in convention presentations and in the field. We also talked to firefighters to find out whether the renewed view is helpful in fighting fires. The theory was well received, to such an extent that the need arose for a written text containing a summary of the principles. The result is this working document.

It is a working document because we still have to find the answers to a number of questions, which we will add at a later stage. At this stage, however, we can already present a number of simple and useful principles for safe and effective firefighting. In fact, these principles are the questions to be answered in the initial size-up; the subsequent answers result in a choice for a specific tactic from the quadrant model and a potential consecutive switch to another quadrant. The basic principles can also be used to evaluate fires and pose the question: "Why was it a success?" In the time to come, the working document will be complemented with the findings of the investigations into gas cooling and smoke explosions.

It is a working document and in order to keep improving this publication we invite you to send your questions or remarks to onderwijscontent@ifv.nl, stating 'The Renewed View on Firefighting'.

I would very much like to thank the members of the study group and all colleagues who contributed to this renewed view. More specifically, I would like to thank the co-authors Siemco Baaij, Edward Huizer and Lieuwe de Witte. I would also like to thank Karel Lambert for his review.

Ricardo Weewer
Professor of Fire Service Science

Contents

Introduction

This working document combines the results of recent investigations by the Brandweeracademie (Fire Service Academy), observations about actual fires, the outcomes of international investigations and the principles of fire safety engineering to arrive at practical basic principles. Since there are no revolutionary new insights involved, we present it as a renewed view on firefighting. In the future, they will simply be known as the basic principles for fighting structure fires. They concern the following findings:

> Under time pressure, people's situation awareness is limited, so we do not notice everything, but we have a kind of narrowed consciousness; this is neurobiologically determined. It explains why sometimes wrong decisions are made. When we take more time, we have the opportunity to register more and interpret what we register correctly (Brandweeracademie, 2015b), and then make a choice for one of the quadrants from the quadrant model.

> We have in fact more time than we think, even if there are casualties involved that need to be rescued. Situations can differ so much that there is always a chance of survival.

> Therefore, we cannot state that a rescue that is executed one minute later is always too late, especially when a rescue can be executed more effectively by taking some extra time (Brandweeracademie, 2015a).

> The offensive interior attack is seen as the standard operational tactic, even if it is not always the safest and most effective attack, which is certainly not the case when the route to the fire is long and the location of the seat of the fire is unknown.

> The most effective way to control a fire is to apply water to it; if a fire is visible from the outside, it is best to do so from the outside (Brandweeracademie, 2017).

> In general, ventilation (air track) is not often enough considered as a size-up indicator (Brandweeracademie, 2016).

> In many instances, the greatest danger, i.e. the supply of oxygen to the fire (ventilation, air track), is not taken into account in the attack technique. Door control is not (yet) generally applied (Brandweeracademie, 2016).

> We notice that the potential power of a fire is not sufficiently taken into consideration and that, as a result, the fire is attacked with too little cooling capacity. When fighting fires in residential buildings, this usually does not cause any problems, except when... (Brandweeracademie, 2016)

> Gas cooling has limitations and is predominantly effective in small spaces[1] (maximally 70 m^2 and with a maximum height of 4 metres) (Lambert & Baaij, 2011). It is important to keep the depth of the attack as short as possible and to apply water to the fire as quickly as possible. Extinguishing the fire is the best form of gas cooling.

> The myth that by ventilating, i.e. opening doors and windows or making a hole in the roof, heat and smoke can be removed, thus enabling an interior attack, often turns out to be incorrect or no longer correct. Most often, it has the opposite effect. Anti-ventilation (keeping a building as closed as possible) gives you more time, also when conducting an offensive interior attack (Brandweeracademie, 2016; Underwriters Laboratories, 2012).

[1] Based on short pulses. By using long pulses, the dimensions might be bigger, but there are no objective data available on this, so we will use these dimensions as guidelines for now.

> With some fire brigades, suppressive ventilation is very popular. Research by Underwriters Laboratories (2016; Weewer, 2017) into the use of ventilation to extinguish fires, shows that a fundamental knowledge of fire behaviour is a must and that this technique is not without risk. Extinguishing fires by ventilation can best be used after a fire is controlled. Furthermore, the fire room has to have a vent. So, the location of the fire has to be known.

The basic principles of the renewed view help firefighters to conduct a safe and effective firefighting attack in practice. Apart from the application in firefighting practice, fire prevention consultants can benefit from these basic principles as well. Using these principles as a starting point provides an insight into the (im)possibilities of firefighting, which subsequently can be used for prevention advice.

1 Basic principles of firefighting according to the renewed view

The renewed view on firefighting aims at a change in thinking during size-up: think from the outside instead of from the inside (search for the fire).
The renewed view does not deny that in many cases an offensive interior attack can still be the best approach, specifically when dealing with residential fires. However, by thinking from the outside, interior attacks are not started without proper consideration, and safer and more effective tactics are not ruled out in advance.

The renewed view consists of five basic principles.[2]

1. Take more time (stop and think).
2. Perform an external size-up with the aim to locate the fire room from the outside and extinguish the fire from the outside.
3. The following three questions need to be answered:
   1. Is the location of the fire known?
   2. Is the fire accessible from the outside?
   3. Is there sufficient cooling capacity?

   The fire can be extinguished from the outside if the fire can be located from the outside, is accessible from the outside and if sufficient cooling capacity is available. If this is not possible, then the building is deemed lost and a defensive attack is the only option. This is usually the case with large buildings.
4. Usually it is safe to carry out an offensive interior attack, under conditions, when dealing with a small building, such as a home or a building consisting of small rooms, and when there is enough cooling capacity available. In that case, think in terms of the SAHF fire triangle.
   > Apply door control.
   > If possible or necessary, apply anti-ventilation (keep the building closed).
   > In case of fire showing, carry out a transitional attack if possible.
   > Apply water to the fire as quickly as possible.
   > Keep the limitations of gas cooling in mind: the shortest distance to the fire.
5. Estimate the potential heat release rate and bring sufficient cooling capacity. Use the rules of thumb for the (potential) heat release rate and cooling capacity needed.

These basic principles are not a ready-made recipe for all fires. That would be impossible because there are many different fire scenarios. However, they are the ingredients to arrive at a safe and effective approach.

[2] Please note that every fire, building and the details of every situation differ in such a way that any one theory can never present all the possible and correct decisions. In addition, during a fire many aspects are uncertain, which leads to the fact that decisions are per definition based on a number of assumptions.

The frame below explains the terms location known, fire accessible, and sufficient cooling capacity.

Location known
During the external size-up signs of flames and locations where smoke is escaping are examined, both with and without a thermal imaging camera (TIC). Doors can be opened momentarily (using the door procedure) to find out whether the seat of the fire is located at the other side of the door. The location of the seat of the fire is known, when flames are observed that are produced by burning materials (and not just by fire gases).

Seat of the fire is accessible
The seat of the fire is accessible when the room in which the seat of the fire is located can be reached from the outside through an opening or an opening in the wall. Water has to be applied directly onto the fire. The opening has to be kept as small as possible. The distance to get to the fire has to be as short as possible because gas cooling is only effective in small spaces.

Sufficient cooling capacity
The cooling capacity that is needed to contain a fire can be determined by using rules of thumb. The rules of thumb are described in Tables 1.2 and 1.3.

The flow chart, including the basic principles, is further discussed in the following chapter.

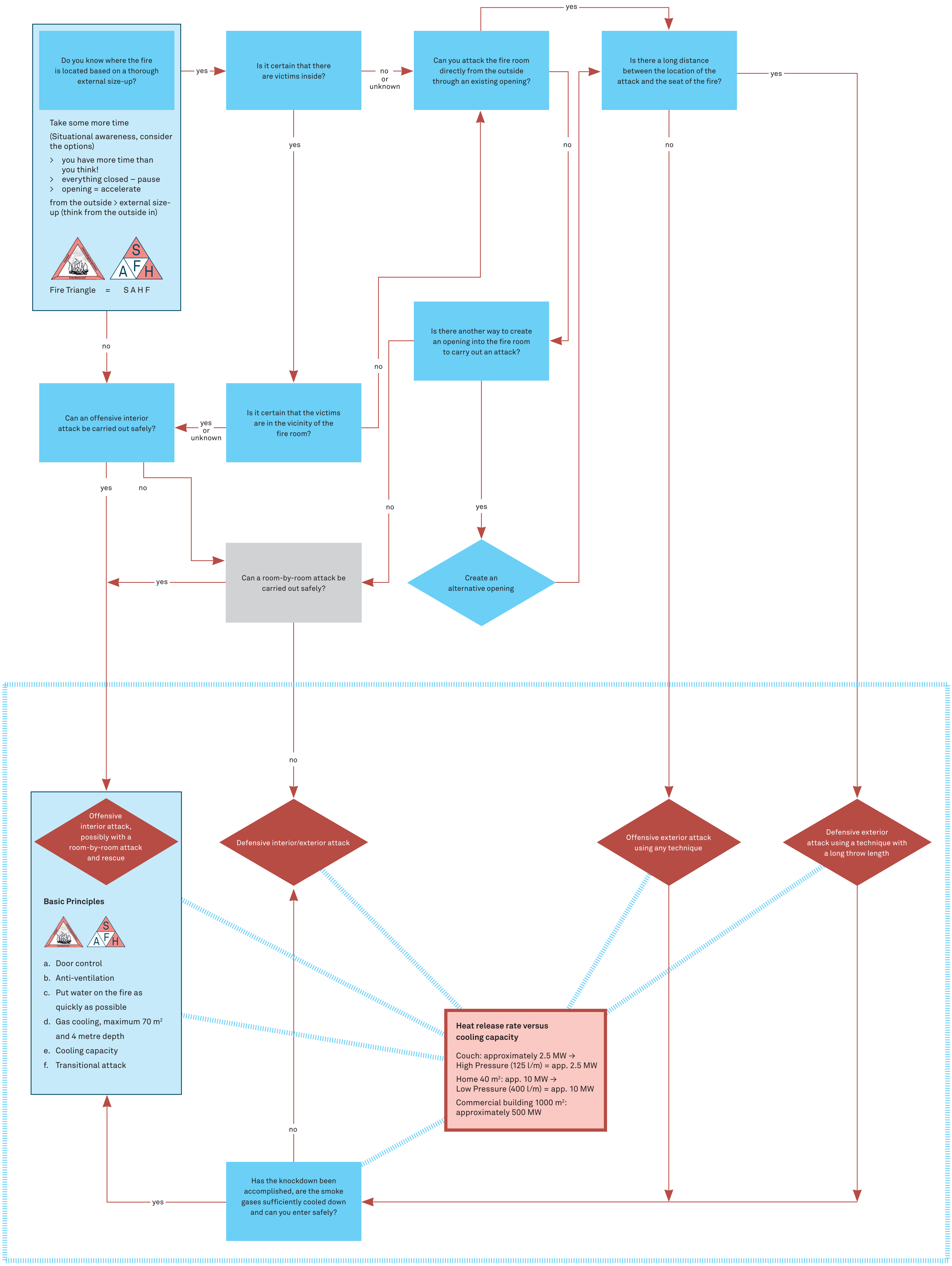

Figure 1.1 Renewed view on firefighting

1.1 Take more time (stop and think)

Decision-making starts with a full external size-up (if possible). Take the time to carry out the size-up and do this before the decision is made to go inside. Research shows that, under pressure of time, people experience a narrowed consciousness, partly due to the effects of adrenaline, which causes them to overlook many vital clues. In actual practice, people tend to follow a routine, even if there are clear signs that this is not advisable. These signs are often missed or ignored.

By taking enough time for a thorough external size-up, the chances that you miss a sign or ignore it because it does not fit into your picture are lowered. In a way, you enhance your situation awareness. For instance, this should no longer happen: 1 and 2 go in with a high pressure hose (and TIC) and do the external size-up themselves, but rather: 1 and 2 perform an external size-up with TIC. Carry out a full external size-up with the aim to find out where the seat of the fire is located, in order to extinguish the fire *from the outside*, if possible.

1.2 Perform a full external size-up with the aim to locate the fire room from the outside and extinguish or contain the fire from the outside

It is best to first approach a fire from the outside. If the seat of the fire can be located from the outside, by performing an external size-up, then it will not be necessary to search for the fire by moving through the building (as is the standard procedure at this time). In carrying out an external size-up, technical devices can be used, such as the TIC. Perhaps other techniques can be developed for this purpose as well. The idea that we are in a hurry is denied by reality. Fires in buildings that are closed do not spread fast. Even if we think there is no time, we can still take some time: by performing a better size-up, we can carry out a safer and more effective attack. Even in cases where a rescue has to be made! An attack at the right location — even if finding the right location takes time — can be more effective than a rapid attack in the wrong location, even after a structure has been opened up or when a fire has created openings.

During the size-up the following three questions need to be answered:

1. Is the location of the fire known?
2. Is the fire accessible?
3. Do we have sufficient cooling capacity at our disposal at the moment?

If these questions can be answered with yes, then the fire can be contained from the outside. In order to completely extinguish the fire, it might be necessary to go inside at a later stage.

However, if the answer to one of these questions is 'no', then the predictable outcome is that the fire cannot be extinguished from the outside and that the building is considered to be lost. It will burn down. Obviously this is a simplified presentation, especially where a rescue is involved, but the key point is that we have to think from the outside in. Possible alternatives are discussed in Chapter 2. The offensive interior attack will be an option more often when there is a fire in an average home or a small building. What is large and what is small depends on the depth of the attack: the distance cannot be too long because gas cooling has only a limited reach. Therefore, the depth of an attack into a room filled with smoke cannot be great (maximally the length of a hose, 20 metres).

Thus, the basic assumption is that an offensive exterior attack is the standard operational tactic from the quadrant model. If necessary, a transition to another quadrant can be made at a later stage of the decision-making process. Figure 1.1 specifies the steps that can be taken.

Research shows that an attack with sufficient cooling capacity in the fire room, or as close to the fire room as is possible, is most effective. So if this can be done, this is the approach to take. As long as the building remains closed, there is still time. Therefore, the adage is: When everything is closed, the fire is at a pause. Creating an opening is to step on the accelerator. So, it is quite all right to take some more time for the size-up in order to arrive at a better assessment of the fire than has been the case in the past. We win back the time for rescue and extinguishing later on, because we can now carry out a more effective attack, which is safer as well. The aim is to first discover the seat of the fire from the outside. At the moment, a TIC is the most suited to accomplish this. Experiments show that this works well if this is done immediately after arriving at the scene. Once the building is heated up, it is almost impossible to detect differences in temperature. The basic assumption is that we have time to carry out a size-up. The idea that we are in a hurry is denied by reality. Fires in buildings that are closed do not spread fast. It is good to take some time because a better size-up facilitates a more effective and safer attack, even in cases where a rescue is necessary.

1.3 Think in terms of the SAHF fire triangle

Basically, the SAHF model contains all the indicators that enable the assessment of burning regime and fire development. However, not all the indicators are easily detectable. The simplification of the SAHF model is based on the indicators that can be detected, i.e.:

> Is there smoke in the room and/or can smoke be seen from the outside (smoke is fuel)?
> Is there an increased temperature?
> Is there a flow path (air track, ventilation, air movement)?

These three elements are in fact the three sides of the fire triangle. When all three sides are present, a fire can suddenly spread.

In actual practice, the sides 'fuel' and 'heat or ignition source' will always be present. The supply of oxygen (air tack) is often the decisive factor for how a fire will develop. Therefore, it is important to limit the supply of oxygen as much as possible, both during an interior and an exterior attack. So door control is of utmost importance. The fire triangle already taught us that, but we rarely use that knowledge in practice. The heat release rate of the fire increases when more oxygen flows towards the fire during a ventilation controlled fire.

Per square metre (m^2) surface area of an opening, 1.5–3 MW of heat release rate can be developed.[3]

By keeping the door closed as much as possible, there is more time to get to the fire and we can approach the fire more safely. This is not always under our control, however. When, for instance, a window breaks or a door burns through, extra oxygen flows towards the fire and the heat release rate can be higher than we estimated. This is why it is essential to take this into account, and to bring sufficient cooling capacity, and move towards the fire as quick as possible (thus keeping the depth of the attack short).

We have to take into account that cold smoke can ignite as well when it has the right properties; that is why we have to regard the side 'heat' as 'heat or ignition source'. This can be important during a defensive interior attack or an offensive interior attack in an adjacent room or compartment when there is a light smoke. The risk of ignition still exists!

1.4 Rules of thumb for (potential) heat release rate and cooling capacity required

When fighting a fire, estimating the potential heat release rate and the cooling capacity that is subsequently needed, might be most vital. This insight is relatively new, even though there is comprehensive literature available on this subject and several rules of thumb were already developed. So far, the textbooks do not have much to say about this subject. This is caused by the fact that to be able to use the rules of thumb, assumptions have to be made. Here, we provide a number of rules of thumb that can be used in practice, still keeping all options open.

Obviously, the heat release rate is partly determined by the amount of oxygen that is available for the development of the fire. The rules of thumb indicate the *potential heat release rate,* i.e. the power that might be generated when sufficient oxygen is available. During ventilation controlled fires, and most fires are ventilation controlled, the heat release rate is not as high. However, when windows break or doors are opened, the heat release rate can increase to the potential power (with 1.5 to 3 MW per m^2 opening). So we have to take this into account. Table 1.2 contains the rules of thumb for determining the potential power.

The cooling capacity is determined by the flow rate and the effectiveness of the extinguishing operation (evaporation). Subsequently, the effectiveness is determined by the branch pipe and the experience of the firefighter handling it. Table 1.3 contains the rules of thumb for cooling capacity; it is based on average effectiveness with the flow rate given. At this time,

[3] This is a rule of thumb based on the formula Q = 1.5 x A x (h)^0.5 in MW that goes for post flashover fires. The part after 1.5 is the 'ventilation factor'; it is derived from Bernoulli's equation that is applied to density current through a single opening. The factor 1.5 is based on the assumption that any kg of oxygen produces a maximum of 13.1 MJ and that there is approximately 23% by mass oxygen present in the air and a mass flow over the opening of 0.5 kg/s. The formula assumes that all the oxygen that flows into the room is used for combustion. This is, of course, not the case; this makes the formula conservative. The rules of thumb are based on an opening with a height of 1 to 4 metres, which can also be considered conservative.

we can only calculate with low and high pressure. Compressed air foam has a higher flow rate than high pressure (133 litres of water per minute) and the cold cut system has a lower flow rate (60 litres of water per minute), but we do not exactly know their effectiveness. As a consequence, we cannot exactly calculate the cooling capacity. Apart from cooling, other physical phenomena might have an effect as well, such as smothering and inertisation. The Brandweeracademie is still researching these subjects.

Table 1.2 Potential heat release rate

Building	Reference Power density [MW/m^2]	Heat release rate [MJ/s or MW]
Average home (low fire load)	0.25	40 m^2 = 10
Average commercial building (high fire load)	0.5 per m stacking height[1]	1,000 m^2 = 500 (1 m stacking height)

[1] This is a value out of the Eurocode, the only documented value available. Experts sometimes use higher values, i.e. 1 MW per metre stacking height.

Table 1.3 Required cooling capacity and extinguishing power of low pressure (LP) and high pressure (HP)

Operational technique interior attack	Actual cooling capacity[3] [MJ/s or MW]	Equivalent heat release rate[4] [MJ/s or MW]
High pressure[1]	2.5	Average couch
Low pressure[2]	10	Standard living room

The rules of thumb are rough target values and can differ per situation depending on the flow rate, effectiveness and success rate. The target values are based on fuel controlled fires. The heat release rate for ventilation controlled fires is lower, but might increase once oxygen is added.
[1] Based on a flow rate of about 125 l/min.
[2] Based on a flow rate of about 450 l/min.
[3] Based on an effectiveness and success rate of 40%–50%.
[4] Based on a maximum heat release rate of an average coach and a living room of about 40 m^2.

1.5 Basic principles during an offensive interior attack

Research in Zutphen, the Netherlands into fire development and survivability has shown that there is no such thing as standard fire development (Brandweeracademie, 2015a). The statistics show us that, on the arrival of the fire service, most fires are still contained in the object or room where they originated. The majority of fires are ventilation controlled; for convenience's sake, we might assume that this is the case when fighting fires. Most of the time we are unable to discern the difference when we are standing in front of the door of the building. The heat release rate of ventilation controlled fires is often smaller than the power that could potentially be generated when extra oxygen is supplied. Consequently, we cannot present a standard recipe for an offensive interior attack. What we can do is present a number of basic principles.

There are in fact three scenarios you might encounter:
1. There is nothing to be seen on the outside of the building.
2. Fire is visible on the outside of the building.
3. Smoke can be seen coming from the building (being pushed out, or spiralling out).

All scenarios can be explained by the stage of the fire growth curve the fire is in at the moment of arrival. However, it turns out that while subsequently we try to determine what actions are needed for each of those situations, in general the same basic principles apply to all of the scenarios. Appendix 2 explains the three scenarios in the context of the fire growth curve. The basic principles are described below.

> Always apply door control and be aware that the extra supply of oxygen (air track) can cause extreme fire behaviour.
> A second technique is to keep the building closed[4] (anti-ventilation).
> Water on fire is the best form of gas cooling.
> Always bring sufficient cooling capacity.
> Keep the distance of the attack route short: gas cooling has its limitations. It is effective in spaces that are not too big, not much bigger than the container in which you practised your techniques (maximally 70 m^2 and with a maximum height of 4 metres, depending on the method used and the knowledge and experience of the firefighter handling the nozzle). When the location of the fire is unknown, apply primarily long, deep pulses; do this from one position in all directions.
> Extinguishing precedes rescuing. Modern fires produce such a large amount of smoke that searching for victims often takes a long time. The fire keeps growing as long as there is no water applied to it. It is a terrible dilemma when we do not know exactly where the fire is located and smoke is spreading fast throughout the building. It might be necessary to evacuate first.
> If possible and necessary, carry out a room-by-room attack. A room-by-room attack is an attack in which, starting from the entrance, every room is isolated by closing the doors and cooling/ventilating the isolated space.
> When there is a blazing fire, a transitional attack is a good option. In a transitional attack, low pressure is used at a maximum flow rate and a solid hose stream is aimed at the ceiling until knock-down is observed, immediately followed by an offensive interior attack. Knock-down has to be accomplished within 20 seconds; otherwise, a further attack is pointless. Most probably, the seat of the fire is located in another room and we are only extinguishing the flames that are showing. The temperature inside becomes more bearable and time is gained for an interior attack. This is vital in cases where the wind is blowing towards the window, for the temperatures inside can be too high for firefighters in their protective turn-out gear to bear.

One of the questions the Brandweeracademie tries to answer and is researching at the moment is the question of which other effects the gas cooling has, other than cooling, for instance the inertisation of fire gases, and what the effect of the formation of steam is. In the US, gas cooling is accomplished by cooling the walls and the ceilings. The question is to what extent this method is effective and to what extent the formation of steam can have a restrictive effect.

[4] By keeping the building closed we can at least gain time to prepare an attack, whether this is a defensive attack, or an offensive exterior attack with specialist material. There is also a chance that the fire extinguishes on its own or that the fire is smothered.

2 The answer to one or more of the size-up questions is 'No': what are the options?

When the answer to one or more of the size-up questions (1. Is the location of the fire known? 2. Is the fire accessible from the outside? and 3. Is there sufficient cooling capacity?) is 'No', in principle we concluded that the building is considered to be lost. Usually, an offensive exterior attack is no longer effective, so we try to find clever ways to change the answers to 'Yes'. But we have to take into account that the fire might spread and that is why we always opt for a defensive attack, a defensive exterior attack to begin with. This is always the sensible choice to make when dealing with commercial buildings, as it is not always necessary when dealing with residential fires, but it has to be kept in mind: in a home, a rapid fire spread can occur via an attic space, for instance. It is advisable to prepare for the possibility that the fire will spread by carrying out a defensive interior attack in those situations. In addition, it is good to keep the building as closed as possible (anti-ventilation); thus, time is gained which can be used to prepare for a defensive attack. There is also a chance that the fire will extinguish by itself. When a building has openings that cannot be closed, for instance as a result of a melting or burning skylight, this is obviously no longer a possibility (unless we find innovative ways to close those types of openings). The defensive exterior attack can be combined with:

- A *defensive interior attack*, with the aim to prevent the fire from spreading to an adjacent compartment (in the same building). Actually, the fire compartment involved is then considered to be lost. Apart from preventing the fire from spreading, it is possible to attempt an attack on the seat of the fire from an adjacent compartment through the fire-resistant structure. Obviously, this is only an option when the structure is compartmentalised, structurally sufficiently safe and when there is sufficient cooling capacity available.
- An *offensive exterior attack*, as an attempt, when the location of the seat of the fire is not known. This is considered an attempt because experiments show that such an attack is not always successful: we cannot be sure that the fire will be contained or extinguished. The aim is to try to control the fire for a short period of time to subsequently either approach the fire from the outside in a better way, or attempt to control the fire at a later stage and extinguish it by means of an interior attack.
- An *offensive interior attack*, in which entering the structure is subject to strict conditions. These conditions are prompted by the SAHF model. In Appendix 1, we show an easy way to use the SAHF model for deciding whether to enter a structure or not. Basically, there are three possible scenarios which, surprisingly, lead to the same basic principles for an attack (see Appendix 2).

The combinations are further detailed below.

2.1 A defensive interior attack supplementary to a defensive exterior attack

The aim of a defensive interior attack is to stop the fire at the compartment boundaries, when the compartment in which the fire is burning, is part of a building consisting of more compartments.[5] First, it is important to establish that the separation construction between the compartments is in fact fire-resistant. Separation constructions often are limited fire-resistant, for about 20 to 60 minutes. Exceptionally, separation constructions can have higher fire-resistant values (up to as long as 240 minutes). Fire-resistance is, however, no guarantee that the fire barrier remains fire-resistant during the attack, the construction of the building itself needs to be fire-resistant as well. A defensive interior attack is aimed at containing the fire inside the fire compartment with the aid of fire partitions. We are not exactly sure how to accomplish this in practice, since there are no techniques scientifically recorded to apply for this goal.

Theoretically, a fire can spread to an adjacent compartment in different ways:

> The load-bearing structure of the fire-resistant partitioning collapses, for instance because the temperature of the steel structure becomes too high.
> The fire-resistant partitioning cracks as of result of which openings are created, through which smoke and fire can spread to the adjacent compartment.
> The fire-resistant partitioning is no longer intact because of penetrations or doorways, or the fire-resistant partitioning is faultily constructed.

Attention!

> Fire-resistant does not necessarily mean smoke-resistant! Lately, we have seen more than before that smoke spreads through joints and cracks in fire-resistant partitions and via all kinds of shafts and ducts in the building. This might be right because in fire prevention, the smoke-resistance of structures is mostly based on assumptions. Partitions as a whole are hardly or never tested on smoke- and fire-resistance. We probably see this more often nowadays since modern fires produce more smoke and become ventilation controlled sooner. The smoke subsequently cools down and we are confronted with less warm smoke which, moreover, behaves differently than warm smoke. In addition, there is more and more scientific proof that at the beginning of a fire, there is overpressure that possibly stimulates the distribution of (relatively) cold smoke via ducts.
> The smoke that spreads to the adjacent compartment is often no longer warm, but this does not mean that there is no longer any danger! Even cold smoke can lead to a type of fire gas ignition if its composition is such that the flammable gas contained in the smoke is between the flammability limits[6]. Depending on the mixture, a smoke explosion might occur when an ignition source is added. This could be any spark with sufficient energy, or fire breaking through the partitioning (as was the case in De Punt, the Netherlands). Therefore, these spaces cannot always be entered safely, and ventilation is not without risk. Ventilating could cause the smoke to get between the flammability limits. In fact, before we enter, we should take steps to ensure that the smoke is no longer a risk, but there is no experience in how to do this and it has not been researched. We do not actually know how to accomplish this. Inertisation with steam or water mist is, at least

[5] A defensive interior attack can also be aimed at enabling the evacuation of a building consisting of more (sub) fire compartments. This situation is not further discussed here.
[6] Fire gas ignition is a term that is used for a group of phenomena that all signify a rapid fire spread. Smoke explosion is one of them.

theoretically, not a solution, because this does not result in a change in composition of the fire gases where cold smoke is concerned. This is only an option when the smoke temperature is far higher than 100°C. For now, we do not have a perspective for action yet, so we always have to allow for a possible smoke explosion.
> Nowadays, many (commercial) buildings are constructed with sandwich panels and roofs consisting of combustible insulating materials. When the fire-resistant partitions are properly constructed, and when they last, the fire compartmentalisation should be okay. Unfortunately, this is not always the case. Fire can spread, past the fire partitions, around the panels. Therefore, the walls and roofs of adjacent compartments have to be checked as well.
> Cooling stone walls or isolated walls is only useful when it happens on the fire side.

2.2 An offensive exterior attack supplementary to a defensive exterior attack

While everything is being placed in position to prevent the fire from spreading to adjacencies or adjacent compartments, an attempt at an offensive exterior attack could be considered, with the resources available, e.g. a cold cut system, compressed air foam or a low pressure jet with sufficient throw length. Of course, we keep the building as closed as possible and the opening we make to execute our attack is as small as possible. The aim can be twofold.

1. We need more time to prepare the defensive attack, for instance when water has to be transported to the scene.
2. We established that an interior attack is too dangerous, but we want to do something.

Note that in the order of decision-making we already established that we are unable to carry out the ideal offensive exterior attack because we do not know the location of the fire, could not reach the location or do not have sufficient cooling capacity. We can no longer guarantee a successful offensive exterior attack, as was shown by the research into the offensive exterior attack (Brandweeracademie, 2017). However, it was shown that under certain conditions some effect could be observed. The firefighting techniques with the longest reach length were the most effective. It is important to note that an offensive exterior attack should be executed in a building that is kept as closed as possible. In fact, it is all about a combination of anti-ventilation and cooling, hoping to hit the seat of the fire, or keep the fire from spreading by:
> smothering the fire by limiting the oxygen supply, and
> cooling the fire gases, and
> cooling the seat of the fire, and possibly
> inertisation of the fire gases with steam.

The idea is that the seat of a fire that is invisible and situated deeper inside the building can still be hit with low pressure (high flow rate and long throw length, but relatively big droplets), compressed air foam (long reach length and turbulence) or a cold cut system (long throw length, high turbulence, possible inertisation). If available, fog nails can be used through the roof or wall, but this should happen in close proximity to the seat of the fire. It may also be possible to gain more time for a defensive attack or for the size-up by trying to contain the fire by using these methods. The building will have to remain as closed as possible. In some cases, just making sure the building stays closed can be sufficient to smother the fire (anti-ventilation). It is a matter of waiting. By applying water, further cooling is accomplished until an interior attack can be carried out to go in and extinguish the seat of the fire definitely.

2.2.1 When to ventilate

Ventilation, whether by natural ventilation, hydraulic ventilation or with the aid of a positive pressure fan, can be carried out in the safest way when the seat of the fire is under control. Theoretically and on paper, beautiful scenarios can be created in which ventilation might be safe, but in practice these scenarios are often hard to assess from outside a building. We need to know exactly where the fire is located, which doors are open and closed, and how powerful the potential heat release rate and the counter-pressure can become. This is why we should not execute a Positive Pressure Attack (PPA). We can ventilate once the fire is under control. We call this PPV, Positive Pressure Ventilation (Underwriters Laboratories, 2016).

2.3 A 'conditional' offensive interior attack

As mentioned before, in some instances an offensive interior attack can be carried out and when dealing with small structures such as homes, it is often a good choice. Under normal circumstances, the steps of a size-up can be executed relatively quickly when dealing with small structures. When we observe that we do not know exactly where the fire is located and/or we cannot reach it from outside, then an offensive interior attack could be considered. However, we always need to have sufficient cooling capacity at hand. We have to be able to always carry out an offensive interior attack safely. The question arises: When is it safe? There is no standard answer to that. We always have to base our actions on our knowledge, so our observations are of importance. The fire triangle provides something to hold on to. The basic principles from Section 1.5 are, as it were, conditions for a safe attack. We do not have a ready-made recipe, but we know what the ingredients are. One of the principles is that the depth of the attack remains limited, as is, in fact, often the case when dealing with small buildings. In executing an offensive interior attack, we follow the basic principles.

For the most part, the basic principles are not new. Current teaching materials largely contain the knowledge, but in actual practice the knowledge is not always applied, or not applied correctly. The SAHF fire triangle and the basic principles should be guiding. In Appendix 1 the simplified SAHF model is discussed in more detail. During a size-up, it is very important to communicate properly about the size-up results in order for the crew commander to thoroughly assess the dangers and decide upon a possible operational tactic. Appendix 1 does not only contain the simplified model, it also contains the language used during a size-up.

On arrival, the most important task is to contain the heat release rate, or power of the fire. This can be achieved by cooling the seat of the fire (cooling capacity and reachability), or by limiting the supply of oxygen. When we think in terms of the fire triangle, then controlling the oxygen supply is one of the most significant tasks we need to focus our activities on. For when there is fire, there is smoke. Smoke is fuel. In addition, there is always heat or an ignition source. The third side, oxygen, is the only side we can manipulate, unless we can attack the seat of the fire directly. We have known this for a very long time, but we do not act on it in practice.

It is an important task to assess and limit the heat release rate and additionally, we have to minimise the heat release rate as much as possible. In order to accomplish this, it is necessary to limit the supply of oxygen as much as possible. This is different from what we are used to doing now, but it is consistent with the knowledge we already possess, and it has again been confirmed by recent research.

2.3.1 Assessing the effectiveness of an interior attack

It is always important to take the *time* to prepare an attack and make a thorough assessment of the situation. And the *fire* always has to be considered in the context of the building in which it is burning. When dealing with fire, the following questions are involved:

> How big is the power of the fire right now?
> How big is the potential power of the fire?
> How much water is needed to control this type of fire?

Tables 1.2 and 1.3 contain rules of thumb to assess the potential power of a fire, and subsequently the cooling capacity needed. Its potential power is determined by the dimensions of the room or the building in which the fire is burning and by the fire load. We use the term potential power because a fire might not be at its most powerful at our time of arrival. When a fire is ventilation controlled, the heat release rate will be lower at that particular stage. This is one of the reasons why, in practice, we still use high pressure when we are extinguishing a fire in a home. Using high pressure does have its disadvantages, for instance when approaching a fire that all of a sudden is supplied with extra oxygen (e.g. due to a window breaking or because the fire has burned a hole in the roof). When this happens, the power grows to the level of the potential power[7] and more water is needed. That is why it is always advisable to take the potential power of a fire as a starting point. This is also why many experts give the advice to bring low pressure. When the power of a fire suddenly increases because of unexpected additional oxygen supply, you will have a greater safety margin of cooling capacity at your disposal.

When dealing with a building, the following questions are involved:

> How large and how high is the building or the room?
> Where are the possible entries located?
> Which materials enclose the structure?
> Are there any fire-resistant partitions?
> Are there any openings in the building and if so, where are they located?
> What is the constructive stability of the building?

[7] When a fire has been under-ventilated for some time at a high temperature, fire gases constitute energy as well. If the gases are released instantaneously in a ventilation induced flashover (VIFO), the heat release rate might be even bigger than the fuel controlled maximum.

2.3.2 Big versus small buildings

In contrast to smaller spaces or buildings, bigger spaces or buildings contain more oxygen at the beginning of the fire development. Here also, the fire will probably become ventilation controlled, but it will take longer. Since it is easier for the fire to develop, the size of the fire will be bigger than in smaller spaces or compartments and the fire will have more power. The exterior size-up should inform firefighters about other entry ways than the front door and perhaps they can see the fire through a window. Those are possible short attack routes to the seat of the fire.

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The Brandweeracademie has published several other reports in English, please visit our website for more information.

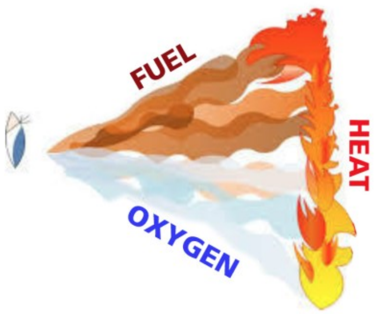
Appendix 1
Communication and the SAHF fire triangle

The simplified SAHF model: the SAHF fire triangle

When trying to more specifically identify the burning regime, it is important to recognise the characteristics of a fire and the possible consequences thereof. In this context, the following is of importance.

> First, we always have to think in terms of the fire triangle. The most basic knowledge is that once the fire triangle is complete, there is fire. That is why we always look at the three sides of the fire triangle.

> The first side is smoke. It is recognisable and essentially, can be considered to be fuel. The second side is the presence or absence of oxygen. And lastly, heat is the parameter we want to keep as far away from us as possible.



The SAHF indicators can help in answering the basic question: Which fire burning regime are we dealing with and can an interior attack be carried out safely? With that, it is important to determine whether a fire is fuel controlled, ventilation controlled or under-ventilated.

The saying "When there is nothing to see, it means nothing" can be misleading when assessing a building, especially when it is entirely closed and the external size-up has not been completed. Especially where under-ventilated fires are concerned, it is possible that there is no longer any 'smoke pressure'.

The SAHF model is based on the fire triangle. Every letter of the SAHF model represents a side of the triangle. The S for Smoke represents fuel, the A for Air Tack represents the supply of oxygen and the H stands for Heat. When all three sides of the fire triangle are at the right (mixing) ratio, the fire gases in the smoke can ignite. This can be observed by the presence of flames (F), the final letter of the SAHF model.

SAHF fire triangle

What we cannot see

We cannot see the combustible gases in the smoke. Most fire gases are colourless, just like oxygen. We also cannot read the mixing ratio. In practice, we do not know exactly when smoke will ignite.

What we can see

When smoke conditions deteriorate, we can see that. It is visible by the change in the density of the smoke; the smoke gets more and more difficult to see through. This causes the combustibility of the smoke to increase. We can also see it when air is streaming in and the temperature is rising.

The SAHF model sums up the indicators with which the burning regime and the fire development can be assessed. However, not all indicators are easily detectable. The simplification of the SAHF model is based on the indicators that *can* be detected, i.e.:

> Is there any smoke in the room and/or can smoke be seen from the outside? (Smoke is *fuel*.)

> Is there an increased temperature?

> Is there any flow (air track, ventilation, air movement)?

In fact, these three elements represent the three sides of the fire triangle. When all three sides are represented, a fire can spread suddenly.

When there is no smoke in a room, there is no (visible) danger. However, this may change. The observation that the smoke density in a room increases is an important size-up result. The situation is deteriorating. When smoke is pushed from a room, positive pressure and high temperature are there. This is one of the ways to observe heat. Obviously, heat can also be felt. Where there is a fire, there is a possible ignition source. Air tack (i.e. supply of oxygen) is always present when there are openings through which air can flow to the fire room.

About cold smoke

It is important to know that cold smoke[8] can ignite as well. In the fire room itself, smoke will usually burn or partially burn, for there is a fire going on. The smoke that has not been ignited consists of a mixture that is often rich in fuel. When the smoke flows into an adjacent room, it can cool down and mix with the oxygen in the air. In those instances, cold smoke can be dangerous because the fire gases can ignite when there is an ignition source with sufficient energy, just like any natural gas. The ignition source can be a spark from an electrical device, but it could also be the fire penetration of a partitioning structure. When the fire gases and the air in the room have the right mixing ratio, then a (cold) fire gas ignition or even a smoke explosion can occur.

New fire triangle size-up

The attack of any fire is based on removing or limiting one or preferably more sides of the SAHF fire triangle. Whether this can be carried out safely in actual practice depends on, among other things, the size of the fire, the available operational power and the building characteristics. It is important to realise that the formation of an image can differ considerably inside and outside a room. That is the reason why at any given moment and in every room, the fire triangle has to be reinvestigated.

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[8] Obviously, smoke here signifies the combination of gases, particles, aerosols and pyrolysis products that have been released or are formed during combustion.

Communicating with the CAN report

Communications about attack strategies and tactics, for instance about which quadrant will be used to fight the fire, have to be clear. This means that everybody in the field has to know what the correct definitions are that are used in incident management. It can never be that the order defensive outside has been given, and that there are still firefighters at work in the collapse zone of the object involved. It is important that fire services use identical terminology to prevent the receiver from doing things the transmitter did not intend him or her to do. The terminology has to contain all the elements that are referred to in actual practice; only then a message can contain all the required information and instruction needed during the incident management for both coordination and execution. Superfluous details should be avoided, but clarity and completeness can never be sacrificed for the sake of conciseness.

By avoiding superfluous words and expressions that do not assign responsibility, the message suddenly becomes perfectly clear. So do not say "aggressive attack to try to keep the fire partition intact", but "attack to keep the fire partition intact". The responsibility is assigned to the team and the team decides how to accomplish this; for that is what they are trained to do. Vague language suggests indecisiveness and results in uncertainty and a lack of confidence.
After a message has been sent, the receiver has to have sufficient time to formulate a response. In the Netherlands, we are familiar with the concept of repeating a message, but how often do we actually do this? By omitting to do so, we omit to verify whether the message has been received correctly. By using the word 'roger' (*begrepen* in Dutch, which means understood) there is no confirmation that the message is understood. It is only by actually repeating the message that it will become fixed in the memory, whereupon a clear response can be given regarding a change in strategy or tactic, or clear expectations are raised.

CAN report

What is observed (sized up) has to be communicated. The same goes for what you do, expect or need. If a crew commander asks for feedback about something or expects something of his crew, then it is very advisable to use a fixed model for communication. This provides handles for both transmitter and receiver to clarify their communication. The so-called CAN report was developed for interaction at an international level. It stands for:

1. the *Conditions* that can be observed,
2. the *Actions* you take or do not take, and
3. the *Needs* you have.

This provides structure to the communication and in three steps everyone involved understands what is meant.

1. Conditions

The first part of the report contains the conditions you observe. You report your location in the building, what is burning, how large the fire is and what the room looks like (potential heat release rate). We use the SAHF size-up language to communicate with each other about the conditions of the fire. Is there any smoke, yes or no (as an example)? The crew commander can ask more in-depth questions to obtain a better image. Is there any airflow?

2. Actions

Different actions might be required based on the findings during size-up of the conditions. We communicate about actions in the second part of our CAN report. What actions have been carried out to gain access to a room? Was there any gas cooling carried out? Were any doors forced open to gain access? A door that was forced open might have been completely removed and this ventilation opening can cause the fire to spread very extensively.

3. Needs

Based on the conditions and required actions, the third part of the CAN report communicates about what (support and means) is needed, where and when.
Maybe a high pressure stream will suffice, or maybe a room turns out to be so large that a low pressure stream is required?

The crew commander can ask more in-depth questions about the conditions, whether there is a fire in a particular room and what burning regime the fire is in. The crew commander can conclude from the actions that a door has been forced open, because of which airflow and fire spread might occur. If conditions were bad to begin with, the fire crew can state that high pressure alone is not sufficient. However, the crew commander can also give the order to pull back and to prepare low pressure.

Table B1.1 Schematic representation CAN report

Conditions	Actions	Needs
> Where are you? > What are the SAHF indicators (clean, heat, air track, fire risk, fire)? > What is burning? > How big is the fire? > What does the room look like? > Special circumstances?	> We finish the task > We extinguish the fire > We search for the victim > Stop exterior attack	> Urgent backup > Relief > Material > Higher water pressure

Table B1.2 An example of a CAN report

	Conditions	Action	Needs
1 and 2	> We are on the second floor at the front > Fuel and heat > We still have 180 bar in the cylinder	> We are searching for the missing person	> Relief
3 and 4	> We are on the first floor > Fuel and air track	> We are taking the stream up	> More length

Agreements on naming the fire conditions (SAHF, size-up terminology)

A first step has been taken in the development of terminology for fire conditions. Communications regarding the size-up of the fire characteristics (SAHF) will vary depending on the knowledge of the transmitter and the receiver. An experienced colleague might communicate that the fire is fuel or ventilation controlled. He or she might also communicate that there is some smoke, but that it is not dense or that ventilation is limited. Everybody will have to communicate unambiguously, so their less experienced colleagues understand and because the crew commander can ask more in-depth questions about the fire conditions. To accomplish this, the SAHF indicators have to be specifically named. We do this in the context of an imaginary SAHF fire triangle.

Clean

A room without SAHF indicators is called *clean*.

Clean

Fuel

Smoke that is no longer transparent, the walls and
the ceiling are no longer visible (smoke conditions deteriorate)
we call *Fuel*.

Fuel

Air Track

When air is flowing towards the seat of the fire and/or can mix with the smoke or fuel in a room, we call *Air Track*.

Air Track

Heat

When smoke/fuel has a high temperature and/or an ignition source is present, then the *Heat* is on.

Heat

Fire risk

When all three sides are on, then the risk of ignition is high.
We call this *Fire Risk*.

Fire risk

Fire

When flames are visible (the SAHF fire triangle is (locally) complete), we call this *Fire*.

Fire

Appendix 2
Three possible situations on arrival

In this appendix, we provide a further substantiation of the basic principles that apply to an interior attack as described in the main document. We try to keep it as simple as possible, i.e. without too many differentiations. But as we all know, a fire is never simple, "It depends..." As is the case with any other model, nuances are lost, so circumstances can be conceived in which the simplification is no longer valid. Still, we are trying to provide a global understanding. We assume that the building is closed and we focus on the fire room or the rooms that are connected to the fire room. From this, it may be concluded that the situation will be different when, upon arrival, you see an open door or window or another type of large opening.

As described in the main document, the following three situations may occur when you are in front of the building.

1. There is nothing to be seen on the outside of the building.
2. Fire is showing on the outside of the building.
3. Smoke can be seen coming from the building (being pushed out, or spiralling out).

In fact, these three situations may occur simultaneously on different locations. You may arrive on the side of the wind pressure and, therefore, see nothing, while on the back of the building flames can be seen and on the side of the building smoke is being pushed out. It is not easy to describe the size-up of a structure fire in statements. For now, we assume that one of the three options occurs at the side of the structure that we are observing.

We have seen that there is not just one standard procedure regarding structure fires, but that the basic principles are applicable to all three scenarios.

1. Always apply door control, i.e. limit the supply of oxygen.
2. If possible, apply anti-ventilation by keeping the building as closed as possible.
3. In case of fire showing, use a transitional attack, if possible.
4. Apply water to the seat of the fire as quickly as possible, taking the shortest route.
5. Assess the heat release rate and determine the required cooling capacity.
6. Apply gas cooling, but only effective in small spaces (< 70 m^2). Keep the distance of the attack route short.

In this Appendix, we explain how we arrived at these principles by describing situations in the terms of the fire growth curve. The stage of the fire at the moment of arrival and the fire behaviour (burning regime) determines what can be observed on the outside of the building. The descriptions are based on the articles by Karel Lambert. They can be found as blogs 20, 21, 28 and 29 on the website of CFBT-BE (Lambert, 2014a, 2014b, 2015).

When sufficient oxygen is present, fires usually fully develop and become almost always ventilation controlled after flashover. In *Brandverloop, technisch bekeken, tactisch toegepast* (Lambert & Baaij, 2011), this is called ventilated fire behaviour. If, on the other hand, there is insufficient oxygen present for the fire to develop, the fire can become ventilation controlled even before flashover. Lambert and Baaij (2011) call this under-ventilated fire behaviour. The fire is then called under-ventilated.
When on the fire growth curve the fire becomes under-ventilated is decisive for what can be observed outside the building. When a fire becomes under-ventilated in a late stage due to sufficient supply of oxygen — and was, therefore, able to grow considerably — then most often the temperature in the room will (still) be rather high. Subsequently, there is a high risk of dangerous fire behaviour upon entry. When a fire becomes under-ventilated at an early stage, for instance because there are no openings or because the fire room is very small, then most often the temperature in the room will be low. This is caused by the fact that the fire was unable to fully develop.

The size of the building affects the fire development. In contrast to smaller spaces or buildings, bigger spaces contain more oxygen at the beginning of the fire development. After a while, the fire will probably become ventilation controlled in this situation as well, but the fire will be able to develop better. As a result, the fire may become much bigger than a fire in a smaller space or compartment and develop and maintain more power because larger buildings have more cracks and joints.

What can be observed on the outside of the building obviously depends on many factors. We will try to provide a broad outline and look at a number of different options for fire development. With the ventilated fire behaviour, we look at the situation after the flashover, the fully developed fire. We assume that this is always accompanied by fire showing. We also assume that the fire is always ventilation controlled. Furthermore, we will discuss three different possibilities for ventilation controlled fire behaviour. The fire becomes under-ventilated at three different moments in the development, i.e. the FC/VC point (the place on the fire growth curve where the fire becomes ventilation controlled) is at a higher temperature. Obviously, this is just an outline, since there actually is a continuum of possibilities. What can be observed, provided that there are any indicators visible outside of the building, depends on our time of arrival. Figure B2.1 depicts these possibilities.

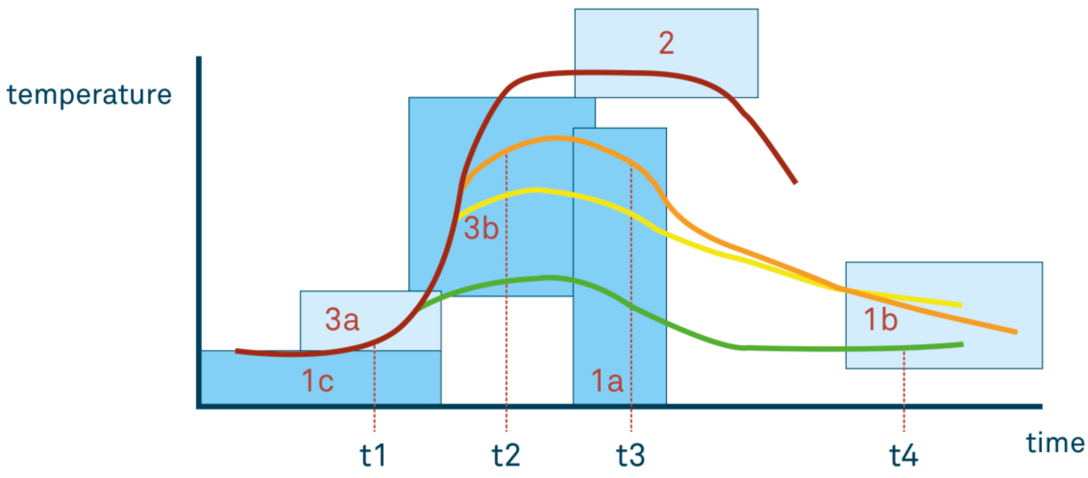

Figure B2.1 Schematic representation of possible scenarios on the fire growth curve

We will discuss the three scenarios separately in the context of observations and focus points. Furthermore, we will discuss the standard operational techniques for each scenario.

Scenario 1: Nothing can be seen on the outside of the building

We are dealing with a fire wherein we arrive at the times t1, t3 or t4. We see no smoke coming out on the outside of the building, but that can be misleading. A well-known firefighter, Ed Hartin, once said: "Nothing showing means exactly that: nothing".
The fire could still be in its growth stage and there is no smoke coming out because the fire has not yet produced that much smoke (time t1). When there is no smoke visible outside, usually this indicates that the fire is still small.
However, it could also be that there is nothing to be seen outside because there is negative pressure on the inside, or the pressure inside and outside is the same. When there is negative pressure inside, the fire probably became under-ventilated just moments ago: fire gases are shrinking because the temperature is decreasing. In case of equal pressure the fire has probably gone out or has been strongly smothered (temperature is low). This is in fact a dynamic process. The negative pressure will only last temporarily because the system wants to equalise the differential pressure by drawing in air from outside. Since there almost always are some crevices or cracks in a building, this is what actually will happen. By drawing in air, the fire can flare up again and smoke will flow outside again. We are then dealing with a pulsing fire, where alternately there is "nothing showing" and smoke coming out.
This might be:

1a. A fire that has not reached flashover yet and became ventilation controlled just before arrival at a high temperature (time t3, yellow or orange line), but is already in the stage of cooling down, or

1b. A ventilation controlled fire that is (almost) extinguished and where the temperature in the room has already dropped (time t4), or

1c. A fire in the growth stage that has produced only little smoke (time t1).

With fire 1a and 1b, you can expect soot marks around the locations where the fire was pushed out.

When the fire has gone out, which according to case histories happens regularly, it is simple. However, a fire can also be almost out, and may flare up again after oxygen is supplied, for instance when we open a door. The crucial issue is that you cannot see this from the outside. This implies that you have to act in accordance with scenario 1a. Some indicators are: visible deposits on the windows and soot marks around the places where smoke could have flowed to the outside; these are signs that there has been a fire.

We have to continue our size-up by opening the door for a short moment. We do so by using the door entry procedure for safe access. However, it is always a good idea to wait for a moment to see whether any smoke is visible. A building is never 100% closed and any differential pressures will always be balanced with the air outside.

Next stage of the size-up: open door (for a short time)

Since it is not possible to determine from the outside whether we are dealing with scenario a, b or c, we have to assume that we are dealing with a fire that has become under-ventilated but might flare up again when oxygen is supplied — by airflow — when a door is opened. It is important to watch what happens when a door is opened, for this is partly dependent on the temperature in the room. When a fire becomes under-ventilated around the time of arrival (scenario 1a) then the temperature might still be high enough to cause ignition. When, on the other hand, this has happened some time ago, the temperature will be much lower and the chance of sudden ignition will be much smaller. It is important to keep paying attention to the signals, more specifically to the air track.

Therefore, we can encounter all four scenarios.

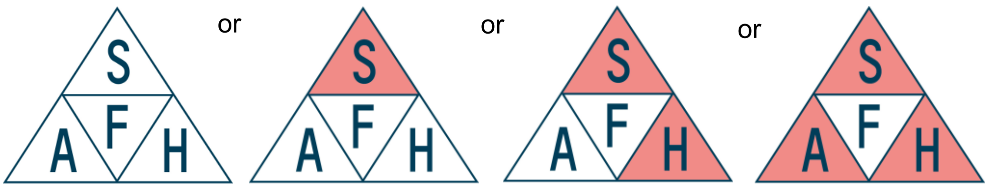

Figure B2.2 CAN report: Conditions: 'clean' respectively: 'fuel', 'fuel and heat' or 'fire risk'

Roughly speaking, there are two possibilities.

> Both fuel (dense smoke) and heat are observed (conditions: 'fuel and heat'). In that case, all the fire needs is oxygen (ventilation, air track). When a door is opened there will be a strong inflow of air inside: an indication that an intense fire has raged and that temperatures are still high. It is of the utmost importance to ensure that the oxygen supply is limited. It might take some time before this effect can be observed, depending on the location of the seat of the fire, for the oxygen has to get there first. After opening the door, the differences in pressure are balanced out and then there are two flow paths: smoke flows out at the top and the air is sucked in at the bottom.

> No fuel or heat is observed and there is hardly any inflow of air (conditions: 'clean' or 'fuel'). Beware: even if there is only fuel (smoke) that is not warm, ignition may still occur! In those instances the limitation of the oxygen supply is still important as a risk control measure, because the fire gases in the smoke might start to fall within the flammability limits when oxygen is added.

Standard technique in every situation: door control

Because it cannot be established with 100% certainty from the outside whether there still is a risk of the fire spreading suddenly, it is essential — and currently this is not common knowledge — to control the air track towards the fire in every situation. That is why the (front) door or any other opening has to be kept as closed as is possible. Door control is a standard operational technique with every fire.

Scenario 1a: The fire has become under-ventilated and is cooling down

Our time of arrival is now t3 in Figure B2.1. No smoke can be seen flowing out the building from the outside. In this case, this is caused by negative pressure inside the rooms. This negative pressure will not persist because air is sucked in through cracks and crevices or other openings. The temperature inside is still high, so the fire will flare up again, resulting in positive pressure. Smoke is pushed out.
To distinguish between scenarios, we can wait a moment to see whether smoke will come out of the building again, or we can briefly open the door to see what is happening.

When we open the door, we will observe both heat and fuel.

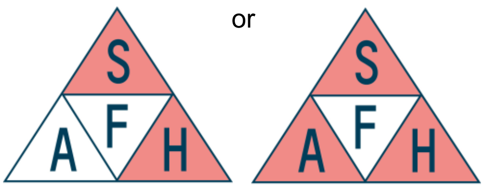

Figure B2.3 CAN report: Conditions: 'fuel and heat' or 'fire risk'

This scenario will be recognisable by a strong air track. Fuel flows out under pressure and a strong air track is flowing in. This is a dangerous situation and it definitely should be considered to not go inside. It is essential that fuel is prevented from igniting when we are inside. For that reason: door control, short depth of attack, long pulses with sufficient cooling capacity.

Background scenario 1a
As a fire develops, changes in temperature and pressure occur. Initially, the temperature and pressure inside the room increase. This can be observed on the outside by the fact that smoke is streaming out. As a fire becomes under-ventilated, temperature and pressure decrease and may even lead to negative pressure in a room. On the outside, nothing can be seen since there is only air flowing in. After some time, the pressure evens out and the temperature falls. This is how a pulsing fire starts; for as soon as the negative pressure ceases to exist, the smoke can flow outside. When a fire has only just become under-ventilated, the temperature can still be high, but negative pressure has been created. When opening a door close attention must be paid, because this is exactly the time when the signals are visible. When a strong inflow of air is observed and the temperature is high (higher than about 200–300°C in the smoke layer) then a ventilation induced flashover can be expected. Pay close attention, because the longer the distance to the seat of the fire, the longer it can take for this to be discernible. Due to this distance, the smoke flowing outside is usually colder than the smoke close to the seat of the fire. So take some time. Only if the fire can be seen from the doorway, you have to immediately apply water to the seat of the fire. The amount of water needed to extinguish the fire depends on its power. This is why it is important to assess in advance what exactly is burning.
When there is hardly any flow to be observed, then the fire has probably been under-ventilated for some time, or the fire is still in the development stage (scenario 1b). There is less danger, especially since the temperature has dropped. The key indicators can be observed upon entry.

Signals
> A strong incoming airflow and exiting of fuel. This can sometimes be heard, but not always.
> High temperature.

Sometimes the signals are alternately visible: on the way to the scene, smoke can be seen coming from the building and a little later it is no longer visible. Here, we are dealing with a pulsing under-ventilated fire and there is a small opening somewhere.

Standard technique: anti-ventilation or door control
In this scenario, door control is the logical technique to apply. Door control means to keep a door closed as much as is possible, also after entry, to limit the flow of oxygen towards the fire. Even if a door cannot be closed completely, it is still the sensible thing to do. The less oxygen that flows to the fire, the lower the power of the fire can become.

If entry is impossible, for instance because the temperature is too high, then waiting (anti-ventilation) is a good alternative. You have actually arrived too soon. This seems counter-intuitive but it is the most effective, especially when there is no one inside the building. By waiting and keeping everything closed, the fire smothers itself and the temperature will drop. Actually, this can take rather a long time with well insulated buildings (hours). An offensive exterior attack can help speed up the cooling down. Incidentally, it has to be borne in mind that even when a building is still closed, the temperature may still be high enough for the pyrolysis of materials to continue. This is why the situation could be even more dangerous when the building is opened up (ventilation and supply of air). We have to take into account that when a building is not closed, the use of a low pressure water spray supplies just as much air as a positive pressure fan and, therefore, we are actually fanning the fire.

When safe entry is possible, an offensive interior attack can be started. Door control remains in force. When approaching the seat of the fire, gas cooling is applied with long pulses. The assessment of the potential heat release rate indicates the flow rate (cooling capacity) that is required for reasons of safety. Here too, the fire should not be located too far inside the building in order for us to keep the depth of the attack short.
If the fire cannot be reached quickly, for instance because it is located too far inside the building and the location of the seat of the fire is unknown, then retreat is the only option.
It remains important to keep observing whether the fire is not close to the point of flashover.
Signals of an imminent flashover:
> an oppressive, increasing heat;
> dancing angels can be seen in the smoke layer (Most of the time this is when we are already too late!);
> a billowing smoke layer;
> visible pyrolysis of objects.

Summary operational technique
> Apply door control.
> Apply anti-ventilation when it is too hot.
> Upon entry bring sufficient cooling capacity (flow rate).
> Apply gas cooling with long pulses when the fire can be approached quickly.
> Apply water to the fire quickly.
> Pay attention to the signals, retreat if necessary.

Scenario 1b: The fire has (almost) died through lack of oxygen and/or combustible materials

In this situation, hardly any smoke will flow out and there is little air track. Usually it is not very hot inside, unless it concerns a room or building that is very well insulated; in that case it can take a long time (hours) for the heat of the fire to have disappeared.

Figure B2.4 CAN report: Conditions: 'clean, 'fuel' or 'fuel and heat'

An object is on fire (chair, couch, cupboard) and:

- the material is burned up and the fire has not spread to other objects in the room; or
- the fire has been under-ventilated for some time due to a lack of oxygen.

These are in fact two scenarios, but it is extremely difficult to distinguish these two situations from each other (See *Casuïstiek ondergeventileerde branden*, Brandweeracademie, 2016). However, a sudden fire spread is still possible. That is why door control is very important, in this scenario as well.

Characteristics

- It is not hot inside the room.
- The smoke/fuel has spread out through the entire space.
- Little airflow (ventilation).
- Soot on the windows and walls from top to bottom.

Operational technique

- Door control.
- Enter as quickly as possible and apply water.

Scenario 1c: The fire is in the growth stage and has produced only little smoke

When the fire is still fuel controlled, it will have produced little smoke and the temperature is still low. Outside the building there will be no smoke visible. On opening the door, the smoke layer will be high up and there will not be a strong outflow of fire gases visible or a strong inflow of air. In principle, we can enter the building to extinguish the fire. However, since it is not possible to observe from the outside as to what scenario we are dealing with, we have to stay alert and watch for signals. We could be dealing with scenario 1a or 3a. The standard principles remain in force and we need to ensure that the fire will not go to flashover due to an extra supply of oxygen.
Signals of an imminent flashover are in this case:

- an oppressive heat;
- dancing angels in the smoke layer;
- a billowing smoke layer;
- visible pyrolysis of objects;
- a fast descending smoke layer.

Scenario 2: Fire showing

When fire is seen outside a building or space that is not too large, such as a home, the fire is usually fully developed (flashover has taken place). This can be observed easily. Usually, a fire becomes ventilation controlled after flashover, but after it has reached its maximum power with the available openings (for a short while). Outside the situation is as follows:

Figure B2.5 CAN report: Conditions: 'fire'

Obviously, the situation inside can be completely different and even differ per room. In general, we can assume that fully developed fires with flames showing are ventilation controlled. If we cannot access the fire from the outside and an interior attack can be conducted safely, then in some situations, after entering, we will have to pass through various rooms to get to the fire room. We have to bear in mind that the circumstances per room can differ, depending — again — on whether the doors are open or closed. Not all spaces may have gone through flashover and we may have to pass through rooms that are filled with hot smoke, which may yet go to flashover once oxygen is supplied. Therefore, door control is required in this scenario as well. In the CAN report, all SAHF conditions are possible.

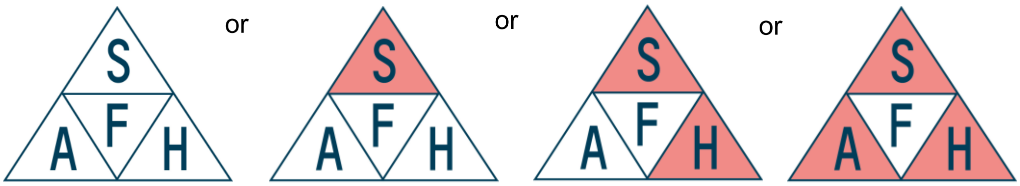

Figure B2.6 CAN report: Conditions: 'clean' respectively: 'fuel', 'fuel and heat' or 'fire risk'

Operational technique

Here, the best technique is a transitional attack. A transitional attack is a combination of an offensive exterior attack and an offensive interior attack. The offensive exterior attack is carried out with a solid low pressure hose stream, with the flow rate set to maximum. The jet is aimed at the ceiling. The operation continues until knock-down is observed. If knock-down is not accomplished within 20 seconds, a further attack is pointless and the attack should be stopped: the seat of the fire is probably somewhere else. The attack has to be well coordinated to ensure that there are no colleagues inside when the exterior attack is carried out.

In case of wind driven fires, there is often no alternative due to the great heat inside. When you are unable to reach the opening where the flames are exiting from, from the outside (for instance, in case of a fire at the rear of a portico flat), then the only option left is to consider an interior attack. In that case, you should act in accordance with scenario 1. It would be an option to execute an attack through a closed door, for instance with a piercing nozzle or a cold cut system, or to use a smoke stopper. If the construction of the building allows you to do so, you can also wait until the fire becomes fuel controlled.

In case of an interior attack, pay close attention to the required cooling capacity (see Tables 1.2 and 1.3). It is essential to make an assessment of what is burning. An entire living room of 32 m^2 can generate a power of approximately 8 MW and this cannot be extinguished with a high pressure jet. In this case, it is necessary to prepare low pressure. Long pulses work best in order to have sufficient reach length for gas cooling.

Rescue

The best time to carry out a rescue operation is after water has been applied to the fire and possible fire triggers have been removed, so the fuel that is still present can no longer ignite. It is only then that the situation is safe to perform a search and to ventilate. The best attacking procedure is: water on the fire, ventilate and search. Obviously, this is not applicable when you accidentally come across a victim. In that case, you have already found the victim and you will lose no time searching for the victim.

When fire is already showing, the construction may have been severely affected. This has to be reckoned with when deciding to go in, or not to go in.

Scenario 3: Smoke coming out of the building

When smoke is exiting from a door or a large window, we may assume that we are dealing with a ventilated fire. We now describe the situation where a building is closed and there is a fire that is most probably ventilation controlled.

Our time of arrival is now t1 or t2 in Figure B2.1. When smoke is exiting from the building, this usually means that there is positive pressure in that location and space in the building, as opposed to the pressure outside. Positive pressure is caused by the fact that the temperature of the smoke exceeds the temperature outside. The pressure difference results in a flow path to the outside. Depending on the height of the temperature and the airtightness of the building, smoke will exit more quickly.

Different situations may occur.
3a. Smoke spirals out. The positive pressure in that location and in that room is limited, i.e. the temperature is not high yet or is not high any longer. The fire is in its growth stage or has cooled down due to a lack of oxygen and is past its maximum power.
3b. Smoke is pushed out. The building is mostly closed. There is an under-ventilated fire that has just become ventilation controlled, but the high temperature is still increasing or has started to decrease only a short time ago.

Scenario 3a: Smoke spirals out (out of openings or crevices)

The fire is (usually) still in the growth stage. When there is an open door, there often is sufficient oxygen available, especially in a small space or building such as a home. Most of the time a little amount of water is enough to extinguish the fire.
A fire that is in the growth stage can often be extinguished with an interior attack. It is important to properly apply the door control technique and quickly bring water on the seat of the fire to prevent further fire development.

When a door or window is opened, flashover might occur within 2 to 4 minutes.

Extinguishing comes before rescuing because it is the quickest way to perform a rescue. When approaching the fire, gas cooling has to be performed. However, this can only be done up to a certain depth. Therefore, apply long pulses. The fire will keep producing energy as long as the seat of the fire is not attacked; so keep paying close attention to the signals.

Signals of an imminent flashover are in this case:
> an oppressive heat;
> dancing angels in the smoke layer;
> a billowing smoke layer;
> visible pyrolysis of objects;
> a low smoke layer or a fast descending smoke layer.

Using the room-by-room attack technique
If possible a room-by-room attack can be carried out. By closing the door between the fire room and the room where you are, you can ventilate the room you are in. Subsequently, the following room can be approached — using the door procedure for safe entry — and so on, until the room with the seat of the fire is found, and water can be applied to the fire. In using this procedure, it is important to watch out for penetrations and/or possible ignition sources connecting with the fire room. Here, a TIC can be a helpful resource.

Operational technique
> Door control.
> Approach the fire using gas cooling, do not go in too deep (distance to the fire).
> Apply long and short pulses.
> Room-by-room attack.
> Apply water to the fire as quickly as possible.
> Extinguish first, cool down, ventilate and then rescue.
> Keep observing to make sure that the fire is not close to the point of flashover.

Scenario 3b: Smoke is pushed through cracks and crevices or openings

Our time of arrival at the fire scene is now t2 in Figure B2.1. When smoke is pushed out of a (usually) closed building, this indicates an intense fire with high temperatures. On the fire growth curve: a fire that has just become under-ventilated. The temperature is already high. This depends on the moment in which the fire has become under-ventilated, so on the amount of oxygen present to allow the fire to grow. Refer to the yellow, green and orange curve in Figure B2.1. The green curve became under-ventilated quickly; the temperature is not yet high. This could be the case with a passive house; there is little oxygen present and there is little supply of air. The orange curve becomes under-ventilated at a later stage and the temperature is high when that happens. The temperature keeps increasing and in the meantime more pyrolysis gases are produced. Obviously, this is a dangerous fire.

Signals
> When a door is opened, smoke (i.e. fuel) will be pushed out due to the positive pressure, until the pressure inside is the same as the pressure outside. This can be observed specifically immediately after opening the door. A tunnel of air will be created due to fresh air flowing towards the seat of the fire, while the pressure evens out and smoke

flows outside. Smoke will exit at the top of the opening; the inflow is at the bottom. At the top, there is positive pressure, at the bottom negative pressure.
> First, the outflow will slow down a bit and cold fresh air flows in. The fire might flare up again because of the supply of oxygen. This might again cause an increase in pressure.

It is hot inside (heat is 'on').

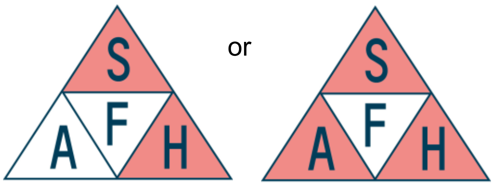

Figure B2.7 Conditions: 'fuel and heat' or 'fire risk'

Operational technique
This fire is potentially very dangerous because a ventilation induced flashover or even a backdraught is threatening to happen.
> Limiting the supply of oxygen is of the utmost importance.
> Anti-ventilation is advised: wait until the fire has cooled down.
> If the seat of the fire cannot be reached rapidly, an interior attack is too dangerous.
> If it is possible to isolate a room quickly by closing a door, then a room-by-room attack can be considered.