IFV
Instituut Fysieke Veiligheid

A second look at foam and water

A study into the fire gas cooling capacity of CAF OneSeven® according to application method 2.0 versus low pressure, high pressure and application method CAF 1.0

Institute for Safety (IFV)
Fire Service Academy
P.O. Box 7010
6801 HA Arnhem, the Netherlands
www.ifv.nl
info@ifv.nl
+31 (0) 26 355 24 00

Publication details

Commissioned by:	Fire Service Academy
Contact:	R. van den Dikkenberg MCDM
Title:	A second look at foam and water. A study into the fire gas cooling capacity of CAF OneSeven® according to application method 2.0 versus low pressure, high pressure and application method CAF 1.0
Date:	7 September 2015
Status:	Final report
Version:	1.4
Authors:	R. van den Dikkenberg K. Groenewegen M. Kobes L. Wolfs
Project leader:	R. van den Dikkenberg
Review and final responsibility:	R. Weewer, Professor of fire service science

Management summary

On 10 September 2013, IFV published the report *Cooling experiments with water and foam*. This is a report of the study into the effectiveness of different fire extinguishants as regards their fire gas cooling capacity. The extinguishants studied were two foam-forming systems (compressed air foam system One Seven® and high pressure proportioning system with foam-forming concentrate Firedos), low pressure (LP) and high pressure (HP).

After the publication of this report from 2013, the supplier of the One Seven® compressed air foam system stated that the method used to apply the compressed air foam (CAF) as applied in the study (short shots or bursts into the fire gas layer) did not match the method advised by the manufacturer and the supplier (applying foam to the walls and ceiling). In conjunction with the supplier, it was therefore decided that the experiments with CAF would be repeated. This new study was conducted under similar test circumstances as described in the report from 2013, with the difference that now the method of applying foam to the walls and ceiling as recommended by the supplier was used. In order to clearly differentiate between these two methods, the method using CAF as studied in the report from 2013 will be designated as CAF 1.0 and the method recommended by the supplier and studied in this report will be designated as CAF 2.0.

The goal of this study is to provide an understanding of the fire gas cooling effect of CAF 2.0 (in accordance with the method recommended by the supplier), compared to LP and HP (in accordance with the CFBT method) and CAF 1.0 (in accordance with the method agreed by the group of experts in a previous experiment). One Seven® was the only compressed air foam system used for testing as part of the study into CAF 2.0[1]. Therefore, the results obtained only concern One Seven®.

The actual research was set up as a laboratory experiment and was conducted in real-world settings. The focus in this research is on analysing any decrease in the temperature of the layer of fire gas, i.e. the research did not consider a fully-fledged, lifelike attack by the fire service.

The central research question was as follows:

How does the effectiveness[2] of CAF 2.0[3], as regards the fire gas cooling effect during an offensive indoor attack in response to a simulated fire in a living room, compare to that of low pressure (LP), high pressure (HP) and CAF 1.0?

As in the previously published report, the degree of fire gas cooling is measured in terms of the absolute temperature trend and in the form of decrease in temperature per litre of water that is introduced.

The experiments showed that, as regards total fire gas cooling, LP caused the greatest absolute decrease in temperature. CAF 2.0 scored less well, but it scored better than HP. CAF 1.0 gave the least fire gas cooling during the total attack.

---

1 Users of other CAF systems are recommended to contact their suppliers for further information about whether these systems can or cannot be used for putting out fires inside buildings.
2 Effectiveness here means the degree to which fire gases are cooled.
3 CAF 2.0 here only refers to the compressed air foam One Seven®.

However, the decrease in temperature using CAF 2.0 was found to vary depending on the actual location of attack. When attacking the *front* part of the container, the absolute effect in the decrease in temperature of CAF 2.0 was comparable to that of HP. These three systems were found to be capable of cooling fire gases to a more or less equal degree when used in the front part of the room through an attack from outside. CAF 2.0 gave a better cooling effect in the front part of the room than CAF 1.0. During the first series of fire gas cooling applications (starting at the entrance to the container), CAF 2.0 reached a greater decrease in temperature *halfway* into the container than LP, HP and CAF 1.0.
Contrary to the other systems, CAF 2.0 already saw a decrease in temperature in the *rear* of the container during the first series of fire gas cooling applications. This means that the attack with CAF 2.0 had a greater effect further into the room.
During an attack halfway into the container as part of the second series of fire gas cooling applications, the further effect of CAF 2.0 was limited, whereas LP and HP showed a decrease. However, CAF 2.0 cooled slightly better than CAF 1.0 during the second series of fire gas cooling applications.

Different amounts of water were introduced while testing, depending on the tactic and the application method. Therefore, the cooling achieved is related to the water usage, which then leads to a statement about the effectiveness per litre of water introduced. LP was found to be the most effective per litre of water introduced, decreasing the temperature by 3.6 ˚C per litre of water introduced. This is followed by 2.3 ˚C per litre for HP, 1.5 ˚C per litre for CAF 2.0 and 1.4 ˚C per litre for CAF 1.0. This means that CAF 2.0 cools somewhat better than CAF 1.0, but it is less effective than water[4].

The above study results lead to the conclusion that fire gas cooling using CAF 2.0 is possible and that this yields better results than CAF 1.0. The added value of the CAF studied (One Seven®) was mainly its fire gas cooling effect deep in the container during the attack as part of the first series of fire gas cooling applications. The further cooling effect was found to be limited in the second series of fire gas cooling applications halfway into the container. This shows that fire gas cooling using CAF 2.0 is possible, but that the fire gas cooling per litre of water introduced is less effective than it would have been if LP or HP had been used.

An increase in temperature was detected while testing using CAF 1.0, as well as combustion of the layer of fire gas. These phenomena were not observed in the tests with application method CAS 2.0.

In order to be able to interpret the results, it must be emphasized that the focus of the study is on fire gas cooling when applying the tactics of an offensive indoor attack in a room of a limited size (comparable to a dwelling), where the seat of the fire cannot be reached immediately. Therefore, the results and conclusions found only apply exclusively to the manner of attacks and test circumstances described in this study. Other application tactics or circumstances may lead to other results. Only statements about the effectiveness of fire gas cooling can be based on this report. No other pre-supposed advantages or disadvantages of CAF 2.0 (One Seven®) compared to water have been studied.

4 One Seven® uses a foam-forming agent and air to convert the water into foam, enabling one litre of water to be converted into 8.7 litres of foam (based on the average expansion rate during the experiments with CAF 2.0).

Contents

1 Introduction

1.1 Background

On 10 September 2013, IFV published the report *Cooling experiments with water and foam*. This is a report of a study into the effectiveness of different fire extinguishants as regards their fire gas cooling capacity. In consultation with the fire service regions involved with that study, the attack tactics for the different fire extinguishants were determined at that time. This was based on the attack tactics that were customary for the tactics in question according to the fire service regions involved. For the experiments with CAF[5] it was decided to apply short shots[6] (1 to 2 seconds) into the layer of fire gas. Based on this method of attack, statements were made about the fire gas cooling capacity of CAF, referred to hereafter as 'CAF 1.0'.
BMT Brandweer- & milieutechniek BV, the supplier of the One Seven® CAF system that was studied, stated after the report was published that the method applied in the study was not compatible with the method recommended by the manufacturer (One Seven® of Germany GmbH). In conjunction with the supplier, it was therefore decided that the experiments with One Seven® would be repeated. This new research was conducted under comparable test circumstances as described in the study from 2013 (see chapter 3), applying the method recommended by the supplier. The method recommended by the supplier of One Seven® is indicated as CAF 2.0 in the present report.

In order to enable a comparison between the results of the experiments using CAF 2.0 and the previous experiments using CAF 1.0, high pressure (HP) and low pressure (LP), the other test circumstances were identical to those of the previous study. Since a discussion had only ensued about the attack tactic when using CAF, Firedos (another foaming agent) that was also used in the previous experiments, has not been considered in the present report. Furthermore, there was no discussion about the part of the report from 2013 that dealt with the fire-extinguishing capacity. Therefore, the present report focuses solely on the fire gas cooling capacity. However, fire extinguishing has been conducted with CAF 2.0. The basic principles of the fire extinguishing test setup differ so much that comparisons with the previous extinguishing tests are not possible. Therefore, the results of extinguishing fire with CAF 2.0 are only presented as facts, without any further analyses or conclusions. These results can be found in annex 1.

5 The One Seven® compressed air foam system, hereafter 'CAF' was the subject of this study.
6 This report refers to 'shot'. In daily practice, people have now started to use the term 'pulse'. Since the results of the present study are compared to the previous study, the term 'shot' will also be used in this report.

1.2 Research question

The research question was as follows:

How does the effectiveness[7] of CAF 2.0[8], as regards the fire gas cooling effect during an offensive indoor attack in response to a simulated fire in a living room, compare to that of low pressure (LP), high pressure (HP) and CAF 1.0?

The degree or fire gas cooling is measured in terms of the absolute temperature trend and by the decrease in temperature per litre of water applied.
In order to answer the research question, experiments were conducted using CAF 2.0 (One Seven®). The results of these experiments are presented in this report and compared to results of the previous experiments[9] from 2013 where CAF 1.0, HP and LP were studied.

1.3 Scope

The research that was carried out for this study concerned one test environment and one scenario. This means that the results of the study only apply to that environment and scenario. The scenario was based on one seat of the fire and that seat of the fire was the only fire load in the premises. There were no possibilities for the fire to spread nor were there any other materials present than clean pinewood (pallets), foam and three sheets of chipboard. To ignite the seat of the fire, one litre of ignition fluid was used each time.

The study looked at two extinguishants, i.e. water and CAF. The tactic applied has a major influence on the effect that can be reached using the different extinguishants. Therefore, the tactics applied were given specific attention while preparing the study. The method for HP, LP and CAF 1.0 applied in the experiments was determined in close collaboration with the team of experts from the regions concerned. The modern jet nozzle tactic as presented in contemporary instruction and learning materials was used for the experiments with HP and LP. The experiments with HP and LP were conducted by a certified CFBT instructor. The method applied for CAF 2.0 was determined in close consultation with the supplier and producer of One Seven®. The supplier also appointed the (certified) jet nozzle operators who applied the tactic agreed.

Different parameters were studied (see section 2.2), including temperature and temperature trends, as part of the experiments. Other parameters, such as relative humidity and pressure in the test object were not measured. The amount of wood actually burnt was also not measured and the composition of the fire gases was not analysed.
The composition/density of the One Seven® compressed air foam used was measured as part of the experiments with CAF 2.0. As this had not been done as part of the experiments

---

7 Effectiveness here means the degree to which fire gases are cooled.
8 As stated above, One Seven® was the only compressed air foam system used for testing as part of this study. Users of other systems are recommended to contact their suppliers for further information about whether these systems can or cannot be used for putting out fires inside buildings.
9 Dikkenberg, R. van den, Groenewegen, K. & Kobes, M. (2013). *Cooling experiments with water and foam*. Arnhem: Fire Service Academy (IFV).

with CAF 1.0, a comparison between the two experiments with CAF is not possible for this aspect. Therefore, this report only presents the results for CAF 2.0.

1.4 Validity of the results

All the systems were tested as part of the fire gas cooling method described in section 2.6. Therefore, the results only apply exclusively to the methods of attack described in this study. Other application tactics can have other effects. The systems were tested exclusively using the jet nozzle and at the pressure referred to above. The use of other pressure, methods or materials can lead to other results. Furthermore, the results only apply to the scenario chosen.[10]

Another aspect to be considered when interpreting the results is that there was a continuous supply of hot fire gases from the seat of the fire towards the exit during the attack. The fact that the temperature rose again whenever a series of fire gas cooling applications was ended was a consequence of this. Actually, this will also be the case due to flows in the event of an actual fire.

1.5 Involvement of the fire service domain, supplier and producer

To make optimum use of the knowledge and experience available in the fire service domain, a team of experts was set up to support the design, implementation and analysis of the study. This team of experts consisted of the professor of fire service science, researchers, and experts from the regions involved. The team of experts defined the test protocol, helped interpret the results and reviewed the draft report.

The producer and supplier of One Seven® were involved in the study into CAF 2.0 to ensure that the correct method of attack was tested. Therefore, representatives of the supplier (BMT Brandweer- & milieutechniek BV) and the producer (One Seven of Germany GmbH) attended a meeting of the team of experts where the exact application of fire gas cooling (and fire extinguishing) was discussed. After this, there was a further meeting of the jet nozzle operators, BMT and One Seven of Germany, and the application method was established. This was fine-tuned during a pre-test.
Representatives of BMT and One Seven of Germany attended the actual tests with CAF 2.0 and supervised the correct implementation of the method. In addition, the supplier and the producer were allowed to inspect the different versions of the draft report and indicate any factual inaccuracies.
Here IFV, in its capacity of independent research institution and financier/commissioning body of the study, assumed an independent position in respect of the supplier.

10 As there were no other pyrolising materials than the seat of the fire, it was not possible for the fire to spread beyond the actual room on fire. Testing was conducted exclusively with one type of fire load in the test setup referred to.

2 Setup of the study

The study focuses exclusively on fire gas cooling when applying the tactics of an offensive indoor attack in a room of a limited size (comparable to a dwelling). The fire gas cooling effects during an offensive indoor attack were studied using four different tactics, i.e. HP, LP, CAF 1.0 and CAF 2.0. The experiment was carried out according to a standard scenario and was repeated five times, with measurements being conducted based on a number of parameters. The scenario was a fire in a living room. To be able to actually measure the fire gas cooling capacity, it was important that the extinguishing agent could not reach the seat of the fire during the fire gas cooling. Therefore, the test was set up in an L-shaped container. The tests using HP, LP and CAF 1.0 were carried out in accordance with the above setup during the prior study[11] in 2013. Additional tests with CAF 2.0 were conducted as part of the present study.
The actual research was set up as a laboratory experiment and was conducted on a realistic scale. The focus was on analysing any decrease in the temperature of the layer of fire gas, i.e. the research did not consider a fully-fledged, lifelike attack by the fire service.
This chapter will go into the details of the test setup and how the research was conducted.

2.1 Systems studied

The tests were conducting using water, applied by means of the low pressure system and by means of the high pressure system, and using CAF via the One Seven® system, applied in accordance with the CAF 1.0 and CAF 2.0 methods. The tactics referred to were studied in the context of an offensive indoor attack[12]. A short description of the systems studied is provided below:

1. Water via the low-pressure system. The low-pressure system introduces 230 litres of water per minute into the room, via a 52mm (interior) hose, applying a pumping pressure of about 7 bar and a jet nozzle pressure of 7 bar. This low-pressure system is abbreviated to LP in this report.
2. Water via the high-pressure system. The high-pressure system introduces 115 litres of water per minute into the room, via a 19mm (interior) hose, applying a pumping pressure of about 25 bar and a jet nozzle pressure of 7 bar. Attacks using high pressure are abbreviated to HP in this report.
3. Compressed air foam via the One Seven® system[13]. Compressed air foam (CAF) is an integrated system on the fire appliance, with a separate hose reel and a jet nozzle. The CAF system mixes water and 0.4% of foam-forming agent[14] under a pump pressure of approximately 8 bar and a jet nozzle pressure of 7 bar, thus converting 135 litres[15] of water per minute into One Seven® foam via a 35mm

---

[11] The results of this study can be found in the report by Dikkenberg, R. van den, Groenewegen, K. & Kobes, M. (2013). *Cooling experiments with water and foam*. Arnhem: Fire Service Academy (IFV).
[12] In accordance with the 4-quadrants model.
[13] Other than in the previous experiments of 2013, a fire appliance fitted with One Seven® OS-C1-100B (OS1200) was used. CAF 1.0 system E2400 PLC was used for the tests in 2013. According to the supplier, this has no effect on the performance during the tests, nor on the comparability of the experiments.
[14] This vehicle configuration was also measured by the supplier.
[15] As stated by the supplier (see also the study in annex 2).

(internal) hose and introducing this into the room via a jet nozzle. The throw length at the start of the attack is some 20 metres, becoming some 15 metres once the pressure has stabilised. In the context of the study, CAF was applied in two different methods.

The LP, HP and CAF application methods are described in section 2.6. Table 2.1 shows the characteristics of the systems used.

Table 2.1. System characteristics

Fire extinguishing system	Brand/type of extinguishant	Jet nozzle	Flow rate and cone angle	Pump pressure used	Jet nozzle pressure	Percentage of extinghuisant mixed in with the water
LP	Water	Akron 1720	230 l/min 30-35°	7 bar	7 bar	n/a
HP	Water	Akron 1711	115 l/min 30	25 bar	7 bar	n/a
CAF	A-class One Seven® of One Seven of Germany	Regular CAF jet nozzle	135 l/min, bound jet[16]	8 bar	7 bar	0.4%

The experiments with LP, HP and CAF 1.0 were conducted during the previous experiments in 2013. The additional experiments with One Seven® in the CAF 2.0 study were conducted in 2014.

2.2 Parameters

The temperature trend was measured, the times were recorded, the water and foam usage was recorded and the visual appearance inside the container was assessed during the experiments. Furthermore, the foam-to-water ratio was measured with every experiment using One Seven® with CAF 2.0. The parameters identified in this section apply to the fire gas cooling. Please refer to annex 1 for the parameters used for describing the fire extinguishing.

2.2.1 Temperature

The following temperature values were measured during the experiments concerning fire gas cooling:

> the temperature at the start of the experiment
> the temperature after the series of fire gas cooling applications
> the temperature trend during the fire gas cooling application[17]

Twelve thermocouples were used for recording the temperatures. They were installed at two different height levels and at different locations inside the container. The outline map (figure 2.2) shows the locations of the thermocouples. Placing the thermocouples in various places in the flow pattern of the layer of fire gas enabled the effect of the fire gas cooling to be

[16] The CAF jet nozzle used does not enable a cone angle to be set; the jet nozzle produces a solid jet bundle.
[17] This can be a decrease in temperature or an increase in temperature.

established, not only in the location where fire gas cooling took place, but also further on in the container (both in the direction of the seat of the fire and in the direction of the exit).

To measure not only the temperature just below the ceiling, but also at a slightly lower level (relevant to systems that apply insulating layers to ceilings and walls), several pairs of thermocouples were placed above one another at various locations. Where pairs of two thermocouples (1-2, 3-4, 5-6, 7-8) are referred to in figure 2.2, the odd numbers are for the thermocouples that are placed the highest (directly beneath the ceiling) and the even numbers are for the thermocouples at a lower level (about 40 cm beneath the ceiling).
To prevent radiation by the seat of the fire leading to a distorted picture, the thermocouples were provided with a guard construction (see figure 2.1) in the form of a hollow square block with an insulating inner layer. The sides of the block were open. The open sides were placed in a transverse direction to the direction of the extinguishing agent to prevent extinguishant from reaching the thermocouples. Comparative tests with and without the guard construction did not reveal any significant difference in the temperatures recorded, but the guard construction was found to effectively prevent contact of the extinguishant with the thermocouples.

Figure 2.1. Thermocouples

Due to their being located near the corner, thermocouples 7 and 8 were reached by radiation from the seat of the fire. Two other thermocouples were placed nearer to the seat of the fire (9 and 10). And finally, in order to be able to return to the initial condition after the experiment, two thermocouples were placed on, (11), and in, (12), the brick wall. The thermocouples were linked to a real-time data logger with a measuring program.

2.2.2 Times

The times were measured using a stopwatch. The time registration was synchronous with the temperature measurement and water usage recorded. Fixed times during the experiments had been established for determining the decrease in temperature per shot (degrees Celsius/seconds) and the duration of the cooling effect during the fire gas cooling.

2.2.3 Water and foam usage

During the experiments, the amount of water used per series of fire gas cooling applications was measured. The water usage was measured using an analogue water meter for the experiments with HP, LP and CAF 1.0 and a digital water meter for the experiments with CAF 2.0[18]. The water meter was reset at the start of every experiment. The water tank of the fire appliance was completely full at the start of the experiment. The water tank was replenished after every experiment. It was replenished through the tank filling pipe into the tank which was operated by a ball valve connected to the tank. The ball valve was shut off immediately when the tank overflowed. The overflow water was collected and measured. This amount was deducted from the amount of water indicated by the digital water meter. The difference was recorded as the amount of water used. The composition/density of the One Seven® foam used was measured for CAF 2.0, but since this was not measured for CAF 1.0, a comparison in this respect is not possible.

2.2.4 Visual appearance

Any specifics of the visual appearance during fire gas cooling were recorded in a logbook. The safety manager and the attack crew made visual observations in the interior. They were asked to share their experiences in a short interview directly after the attack. The attack crew used a thermal imaging camera to record video footage during the experiments.

Other parameters

Furthermore, the following parameters were measured in order to be able to analyse the reproducibility of the experiments:

> starting temperatures in and on the wall;
> maximum temperature between ignition and the start of the experiment.

2.3 Test object

The tests were carried out at the Troned practice centre. The test setup was the same as that used in the previous study[19]. It resembled the scenario of a fire in the home as closely as possible.

The test object is shown in figure 2.2. A specially prepared L-shaped container was used that was partly fitted with a brick inner wall. Both sides of this L-shaped container were 9.0 metres long, the container was 2.30 metres wide and its height was 2.25 metres throughout. The part where the fire was lit was 2.0 metres wide and had the same height and depth. The total surface was 35.5 m^2 and the volume was 79.9 m^3.

---

18 During the experiments with CAF 2.0, it was found that the analogue water meter was not compatible with the fire appliance used. Therefore, a digital water meter was used for these experiments. In order to be able to compare the results measured by the different water meters, Kiwa conducted a calibration test afterwards, see section 4.3 and annexes 2 and 3.

19 Dikkenberg, R. van den, et al. (2013). *Cooling experiments with water and foam*. Arnhem: Fire Service Academy (IFV).

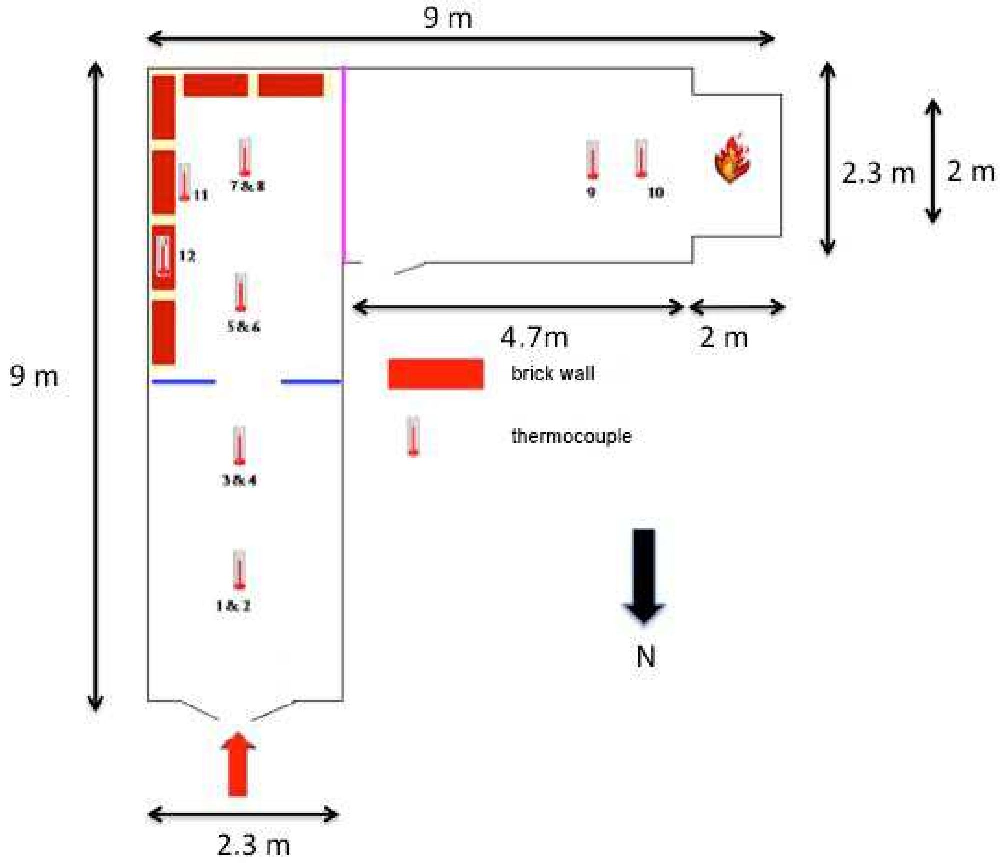

Figure 2.2. Floor plan of the test object

The rear part of the steel L-shaped container (see figure 2.2) was equipped with concrete building bricks on two sides to create a 20-cm brick wall. The aim was to simulate a realistic situation. As the heat properties of a brick wall are different from those of a steel wall, the wall was built from floor to ceiling and secured safely.

Because the experiments were performed in an L-shaped container, direct contact between extinguishing agent and the seat of the fire was not possible during the fire gas cooling. This made it possible to cool fire gases in the front part of the container without the extinguishing agent having any direct effect on the seat of the fire.

2.4 Fire load

A fire load was created in the container by starting a fire consisting of seven pallets of 121 cm x 102 cm x 12 cm (approx. 130 kg of pinewood), one foam mattress[20] (size 100 cm x 100 cm x 21 cm), three sheets of chipboard (size 120 cm x 100 cm x 1.2 cm) and a litre of ignition fluid. This local fire load was about 2,600 MJ (equivalent of about 155 kg of pinewood) and placed on a surface of about 4 m² in the living-room fire scenario. The fire load consisted of wood and polyether foam. The foam mattress was added to add maximum realism to the situation.

20 HR polyether foam from the Recticel company, foam type R37130, density 33-36 kg/m³. The basis for polyether foam is polyurethane. Polyether is mainly used as seat stuffing and for mattresses.

The fire load was composed as follows: four pallets at the bottom, then a sheet of chipboard, then the foam mattress, then another sheet of chipboard, then three pallets and finally another sheet of chipboard. See also figure 2.3.

The fire load was ignited according to a fixed pattern. Half of the ignition fluid was spread onto two softboard ignition strips. The remaining ignition fluid was sprinkled onto the four lower pallets and then the ignition strips were lit and slid under the pallets.

Figure 2.3. Composition and ignition of the fire load

2.5 The initial situation

After lighting the fire load, the fire started to develop. Initially, all the doors of the container were open to provide the fire with sufficient oxygen. The door that was closest to the seat of the fire was closed quite soon after the fire started to grow. Then the temperature started to increase. The first door on the attack side was then closed at a certain point in time[21]. This created a layer of fire gas. If the temperature on thermocouple 3 remained higher than 250 ºC, the second door on the attack side was closed as soon as the fire gas layer was thick enough[22]. Then there was a 30-second waiting period while monitoring whether the temperature on thermocouple 7 remained at around 500 °C. If this was the case, the doors were opened after 30 seconds and the fire attack was started.

2.6 Conducting the experiments

The fire gas cooling experiments were conducted five times. The fire gas cooling procedure consisted of two series of 30 seconds each. The first series was conducted at the access doors, the furthest removed from the seat of the fire. The second series was conducted halfway into the container. The setup of the fire gas cooling experiments was such that direct contact with the seat of the fire was not possible. The specific application methods for the individual systems were determined and followed during the tests.

---

21 Based on the colour of the flames changing from yellow to red and a mixture of flames and soot over the seat of the fire.
22 With the help of a marking on the wall of the container, at 110 cm from the floor.

2.6.1 Fire gas cooling using HP and LP

Fire gas cooling using high pressure and low pressure was carried out in accordance with the regular CFBT procedure. Every series of fire gas cooling applications consisted of 3 x 3 short shots of approx. one second where water was introduced into the layer of fire gas at an angle of 45 degrees, using a jet nozzle with an approx. 30-degree cone angle.
Three shots were applied in the first series from the entrance door, at t = 0 (where t = seconds), and the next two sets of three shots at t = 10 and t = 20. The team then advanced to the second positioning line (blue line in figure 2.2, blue arrow in figure 2.4) where the second series of 3 x 4 shots was applied at t = 30, t = 40 and t = 50 respectively.

Time	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Action		3 shots		3 shots		3 shots		3 shots		3 shots		3 shots	
Location		At access door to container					→	Halfway into the container					

Figure 2.4. HP and LP attack methods using 1-second shots

2.6.2 Fire gas cooling using CAF 1.0

Fire gas cooling using CAF 1.0 was conducted by applying the shots (one to two seconds) in the room with a bound jet, aimed into in the layer of fire gas.
Due to the power and throw length of CAF, it was decided that the first set of fire gas cooling applications would be carried out at the access door at seven metres from the opening, so that the extinguishant would end up in the layer of fire gas in the front part of the container. In the first series,
three shots were applied at t = 0, and the next two sets of three shots at t = 10 and t = 20. The team then advanced to the second positioning line (blue line in figure 2.2, blue arrow in figure 2.5) where the second series of 3 x 4 shots was applied at t = 30, t = 40 and t = 50 respectively. Prior to every experiment, the hose was rinsed outside the container in order to make sure that the mixture in the hose would be homogeneous.

Time	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Action		3 shots		3 shots		3 shots		3 shots		3 shots		3 shots	
Location		At access door to container					→	Halfway into the container					

Figure 2.5. CAF 1.0 method of attack with shots of one to two seconds

2.6.3 Fire gas cooling using CAF 2.0

Every series of fire gas cooling applications consisted of two long shots of five seconds[23] in a crescent-shaped movement, applying foam to the walls and the ceiling of the container using One Seven®. The first series consisted of individual shots being applied from the access door at t = 0 and t = 15 seconds. The team then advanced to the second positioning line (blue line in figure 2.2, blue arrow in figure 2.6) where the second series of long shots was applied at t = 30 and t = 45 respectively. The setup of the fire gas cooling experiments was such that direct contact with the seat of the fire was not possible.

Time	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Action		Crescent			Crescent			Crescent			Crescent		
Location		At access door to container					→	Halfway into the container					

Figure 2.6. CAF 2.0 method of attack with crescent-shaped movements of 5 seconds

23 Approximate value. Due to the setup chosen, differences will have occurred at these times indicated. See also annex 2.

2.7 Uniformity of study conditions

The procedure described, of building, lighting and monitoring the fire development, was followed to ensure that all initial situations and experiments were comparable and uniform. For example, the pallets came from one batch and were stored under similar conditions prior to the test. The same applied to the foam mattresses, sheets of chipboard and ignition fluid that were used. To guarantee continuity and unambiguity, the same people were used to build and light the fires.

Experienced fire fighters with state-of-the-art training and education in operating the system in question were used for each system. To ensure that every attack would be performed in the same way, agreements about how to perform the attack were made with the experts from the regions involved in advance.

The room was reconditioned after every attack by performing the following actions:

- removing the remains of the fire from the room
- removing the extinguishing agent from the room
- cooling the walls and the air until all the thermocouples indicated temperatures of below 100 ˚C.

When reconditioning the room, a fan was used for further cooling, as well as squeegees to remove the extinguishing agent and return the room to its original state as far as possible. As the container was cold and dry at the beginning of the day, in contrast with its use later in the day, a test fire was set at the beginning of every day in order to warm up the container. This fire was then extinguished to create a comparable relative humidity.

2.7.1 Meteorological circumstances and the use of water meters

Although a lot of attention was paid to the uniformity of the experiments, there were two aspects that were not entirely identical in the experiments, i.e.: the meteorological circumstances and the use of the water meters.

The meteorological circumstances were not constant[24] during this experiment and they could not be compared to the circumstances during the previous study. There was little wind or strong wind, rain or no rain at all, and different temperatures on different days and at different times of the day. The weather conditions on the test days can be found in table 2.2.

Although there were differences, their influence on the tests is expected to be so little that the results obtained can still be used for the research. The wind direction was away from the door opening on all days of the test. The relative humidity and pressure were not measured in the container.

[24] An analysis of the meteorological information of the KNMI weather station at Troned showed that there were differences. This is something that cannot be prevented in practical experiments outdoors.

Table 2.2. Measurement information of the Twente KNMI weather station (290)[25]

Date	Wind direction (degrees)	Wind speed[26] (m/s)	Temperature[27] (˚C)	Precipitation[28] (mm)	Relative humidity[29] (%)	Average air pressure (hPa)
29 Jan '13 (CAF 1.0)	SW (222°)	5.8	10.2	5.7	93	1004.7
31 Jan '13 (LP+HP)	WSW (238°)	7.0	6.7	11.7	79	1009.1
01 Feb '13 (HP)	SW (234°)	3.8	4.9	5.7	91	1000.0
10 Feb '14 (LP ref)	SE (128˚)	2.6	4.5	0.2	79	995.6
11 Feb '14 (CAF 2.0)	SSW (208˚)	4.9	5.6	1.1	82	999.6
13 Feb '14 (CAF 2.0)	SSW (206˚)	5.0	5.0	4.0	84	994.6

A second aspect in which the experiments differed was the water meter used. An analogue water meter was used in the first study, whereas a digital water meter was used in the present study. To be able to compare the water usage rates of the two experiments, both water meters were tested by an independent research institution, i.e. Kiwa, and comparison tests were conducted. Both Kiwa and the comparison tests demonstrated that the results measured by the two meters are comparable.

It is true that two other matters were different, but these matters are assumed to not have influenced the experiment or the results.
Both the experiments from 2013 and the current experiments showed that a fixed schedule for opening and closing ventilation openings does not lead to identical fires. As the fire growth is influenced by such factors as the ambient temperature, relative humidity, wind force and wind direction, it is hard to achieve exactly the same fire growth outside a laboratory environment, in spite of the identical fire load. In order to achieve the right temperature, it was therefore decided, based on observations by experts in the start-up phase, that the ventilation conditions should be adjusted to the actual fire development until the conditions referred to above had been reached. From that moment onwards, the protocol established for reaching the starting condition would be followed. A comparison of the starting temperatures, the maximum temperatures and the length of time of the heating phase (see chapter 3) has shown that there were no significant differences between the experiments.
Furthermore, another, larger fire appliance was used for the experiments with CAF 1.0 than for the experiments with CAF 2.0. The supplier of the One Seven® foam studied has confirmed that both fire appliances emit the same extinguishant from the jet nozzle at the same force and flow rate, enabling the results of these two experiments to be compared.

---

[25] Source: http://www.knmi.nl/klimatologie/daggegevens/index.cgi
[26] 24-hour average
[27] 24-hour average
[28] 24-hour aggregate
[29] 24-hour average

2.8 Data analysis

After the experiments were ended, the data of the thermocouples, the time and water records, the experience gathered from the interviews, the specifics from the logbook and the visual appearance recorded using cameras (one thermal imaging camera and several digital cameras) were all assessed.

Before assessing the effect of CAF 2.0 on fire gas cooling, the extent to which the results of the five experiments that had been conducted matched each other was first studied. If the results of the five experiments were found to be largely compatible with each other, this would say a lot about the reproducibility[30] of the study or the fire extinguishing system. It would also say a lot about the possibility of making reliable statements about the study.
A significance test was conducted in order to analyse the differences. The Anova test was used in this case. This test makes it possible to calculate the probability of a difference that is found being a coincidence. The reliability percentage chosen was 95 percent, in other words: if the error probability (p) found is less than 0.05 (5 percent), the difference is considered to be a significant difference. The probability that the difference found is an actual difference and not a coincidence is greater than 95 percent. This is expressed in the value for p. In addition, a value is calculated for F. This expresses the size of the difference. No further interpretation can be based on the value for F.

The next step was determining the extent to which certain experiments, for which the logbook or the description of the people involved showed that something special had happened that did not belong to the actual experiment, should be included in or excluded from the analysis.
Then the fire gas cooling applications were analysed. Here both series of fire gas cooling applications were considered separately, as well as the temperature trends during the entire attack. The results were compared to the results of the previous experiments using CAF 1.0, HP and LP.

When interpreting the data, it is important to know that, like any other study, this study has its limitations. For example, there were no materials that released gases, other than the seat of the fire. And as a result, it was not possible for the fire to spread to beyond the direct room where the fire was lit. Testing was conducted exclusively with one type of fire load in the test object referred to. Chapter 5 provides some further interpretation of the results.

30 The degree to which you get the same value if the experiment were conducted again, and, as a result, whether the results are reproducible.

3 Reproducibility of the experiments

Before comparing the results of the study using CAF 2.0 from 2014 to the results of the previous study from 2013 using CAF 1.0, HP and LP, it was assessed as to what extent the fires and the interventions of the different studies could be reproduced. Three aspects were considered:

1. Whether the test conditions of the first test week and the second test week were similar. The LP reference experiment was therefore studied to see whether it was compatible with the previous LP experiments.
2. Whether the fires used in order to test the different tactics were similar as regards their starting temperatures. This was necessary in order to be able to compare the effectiveness of the systems tested.
3. Whether the five instances of attack using one specific tactic are reproducible, enabling the average values to be calculated.

3.1 Similarity of circumstances in the weeks when the tests took place

In order to be able to compare the results from the previous study (2013) to those of the current study with CAF 2.0, the setup of the experiments with CAF 2.0 was made identical to that of the previous study. The only difference was the method used when applying the One Seven® CAF being studied. However, in order to take away any doubt as to uniformity, a reference experiment with LP was carried out. If the results of the reference experiment with LP were comparable to those of the previous experiments with LP, this was sufficient proof that the study situation matched that of the previous study and that the experiments with CAF 2.0 and the results from the previous experiments with CAF 1.0, LP and HP could be compared to each other.
Table 3.1 compares the starting temperature and the final temperature of the previous experiments with LP to the reference experiment with LP. Analogous with the previous experiments, the values were measured on thermocouples 5 and 7.

Table 3.1. Summary of temperatures of previous LP experiments and the reference experiment with LP

Experiment	Starting temperature TC 7	Starting temperature TC 5	Final temperature at t=55 s on TC 5
LP 1 (2013)	497	340	195
LP 2 (2013)	507	328	178
LP 3 (2013)	490	332	203
LP 4 (2013)	522	338	210
LP 5 (2013)	509	321	187
LP avg. 1-5 (2013)	505	340	195
LP reference (2014)	492	338	173

The statistical analysis showed that the starting temperature on thermocouple 7 in the reference experiment was not significantly different than the starting temperatures in the previous experiments (F = 0.942; p = 0.387). This was also true for the starting temperature on thermocouple 5 (F = 0.541; p = 0.503) and the final temperature on thermocouple 5 (F = 2.425; p = 0.194).

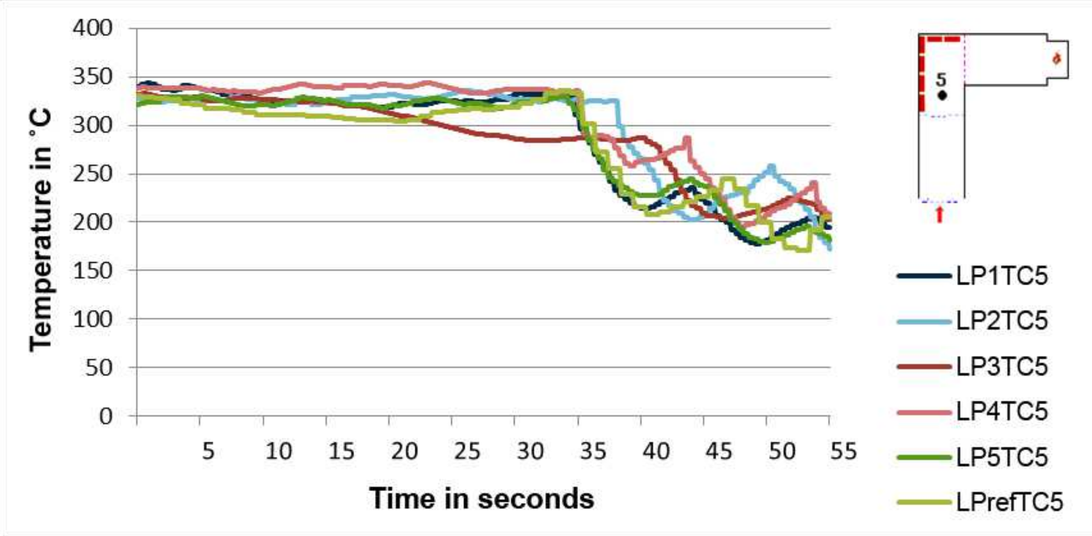

Figure 3.1. Reproducibility of the LP experiments: reference experiment versus previously conducted experiments in the same test setup

Figure 3.1 shows the temperature trend of reference experiment LP refTC5 plotted into the same graph as the earlier experiments with LP. The figure shows that the temperature trend of the reference experiment was comparable to that of the other experiments.

3.2 Reproducibility of the fire growth

Tables 3.2 and 3.3 show the starting temperatures, the minimum and maximum starting temperatures, and the average time of the heating phase.

Table 3.2. Starting temperature (˚C), per fire extinguishing system

Fire extinguishing system	Average starting temperature	Minimum starting temperature	Maximum starting temperature
CAF 1.0	512	496	522
CAF 2.0	501	469	531
Low pressure	504	491	518
High pressure	504	493	530

Table 3.3. Temperature (˚C) and time (sec) of start-up phase, per fire extinguishing system

Fire extinguishing system	Average maximum temperature in start-up phase	Average duration of the heating phase in seconds
CAF 1.0	524	550
CAF 2.0	528	500
Low pressure	521	533
High pressure	521	553

A statistical analysis shows that there are no significant differences between the starting temperatures
($F = 0.376$; $p = 0.0.772$), as well as the maximum temperature ($F = 0.367$; $p = 0.778$) and the duration of the heating phase ($F = 0.209$; $p = 0.889$). The above shows that the fire growth prior to the attack was virtually identical.

3.3 Reproducibility of the attacks

The attacks were repeated five times and the extent to which the results of these five experiments were compatible with each other was examined. To analyse reproducibility, the temperature trend of the total fire gas cooling attack at the location of thermocouple 5 was studied. As this thermocouple was located halfway into the container where it was not directly reached by radiation from the seat of the fire, thermocouple 5 gave the best total summary of the fire gas temperature and any possibility of it being heated by radiation from the seat of the fire was limited. This thermocouple was also used for the analyses in the previous experiments with CAF 1.0, LP and HP.

Figures 3.2, 3.3, 3.4 and 3.5 show the temperature trend during the experiments. These figures outline three variances when comparing the five experiments:

- > the variance on the horizontal axis (as regards time)
- > the variance on the vertical axis (as regards temperature)
- > the curve trends.

The curve trends are important for the reproducibility of the experiments. This is visible in the wave pattern that is, or is not, followed by the lines of the individual experiments and in how steep the decreases and increases in temperature are.
The horizontal and vertical shifts are caused by the differences in starting times and starting temperatures and are not relevant to the reproducibility, provided that the wave patterns and the steepness of the decreases and increases in temperature are comparable. This can be explained as follows:

- > The variance on the horizontal axis is visible as the moment when the temperature decreases or increases. These variances are caused because the interventions (series of shots) of the individual experiments were not carried out exactly at the same time.
- > The variance on the vertical axis is visible in the height of the temperature. This variance in the height of the temperature is caused by, sometimes minor, differences in starting temperature.

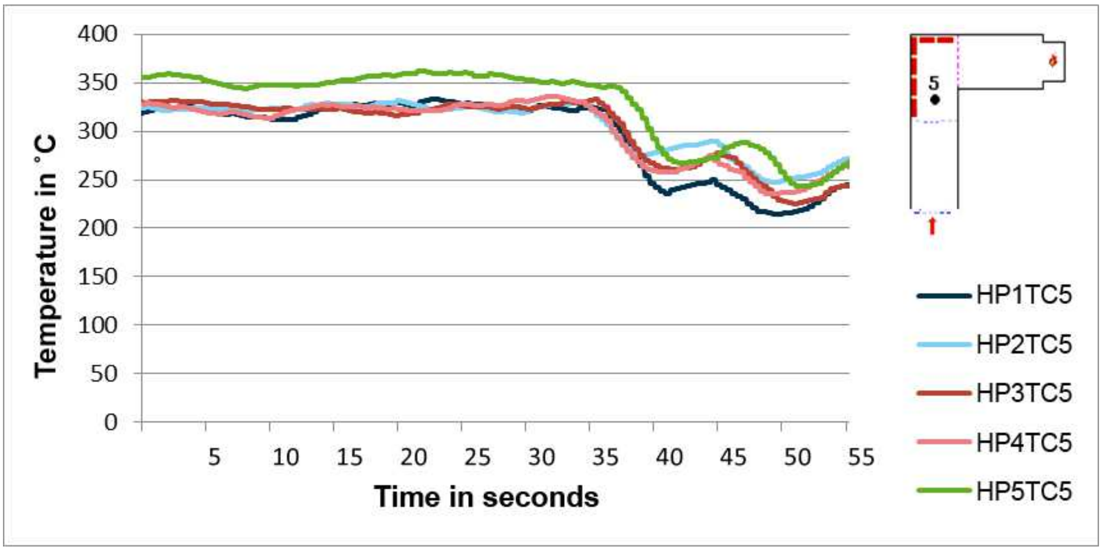

Figure 3.2. Reproducibility of HP experiments, fire gas cooling, thermocouple 5

Figure 3.2 shows the tests with high pressure. This shows that test HP5 has a higher starting temperature, but that the further trend is comparable to that of the other four tests.

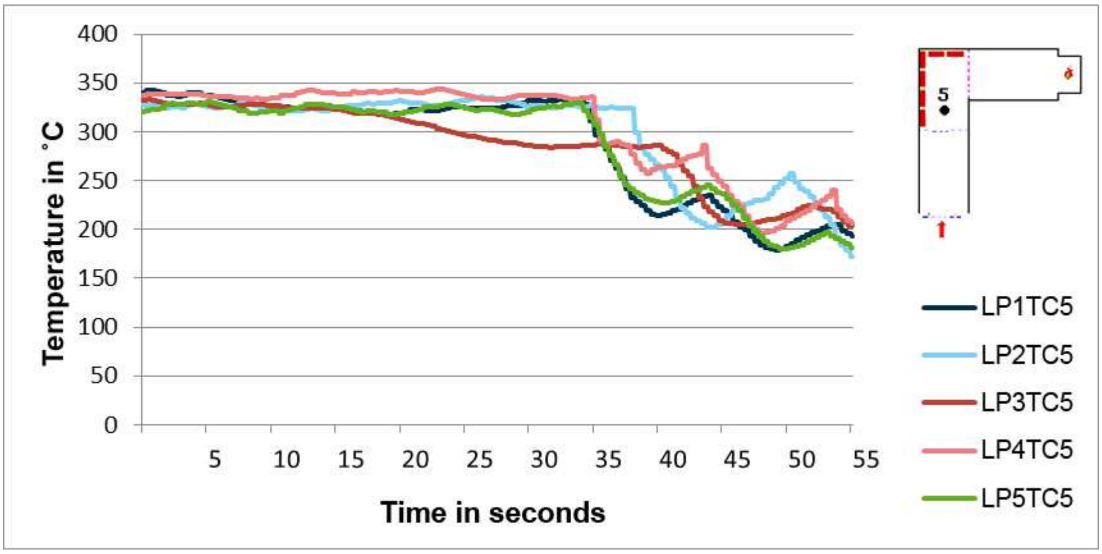

Figure 3.3. Reproducibility of LP experiments, fire gas cooling, thermocouple 5

Figure 3.3 shows the tests with low pressure. Test LP3 shows a deviating decrease in temperature in the first series of interventions, but otherwise it follows the pattern of the other tests.

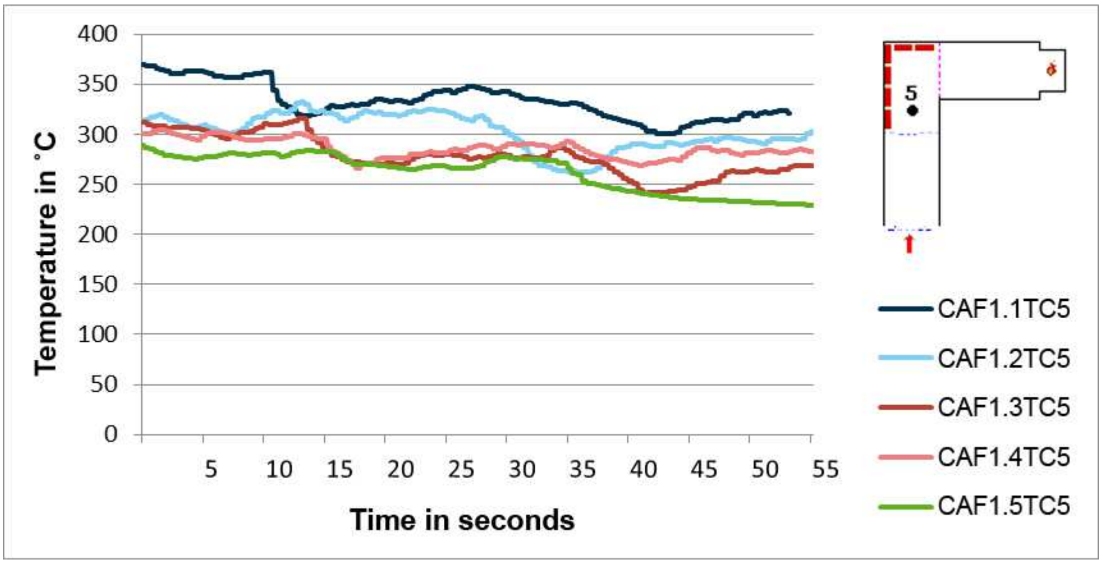

Figure 3.4. Reproducibility of CAF 1.0 experiments, fire gas cooling, thermocouple 5

Figure 3.4 shows significant variance in the temperature trends of the five tests. Furthermore, the trends are rather erratic in all the tests right from the start. The tests CAF1.1 and CAF1.2 differ the most from the other three tests. When asked, the attack team reported that some foam landed *next to* the container during the first series of fire gas cooling applications in the first test. An analysis of the first fire gas cooling application did show a deviation on thermocouple 1 of test CAF-1. As a result, it was decided to not include the first CAF test (CAF-1) in the analysis. No explanation was found for the deviation in CAF-2 since the attack team did not report anything special in the performance of the test. Therefore, the average line in the following chapters is based on the tests 2 to 6 of CAF1.0.

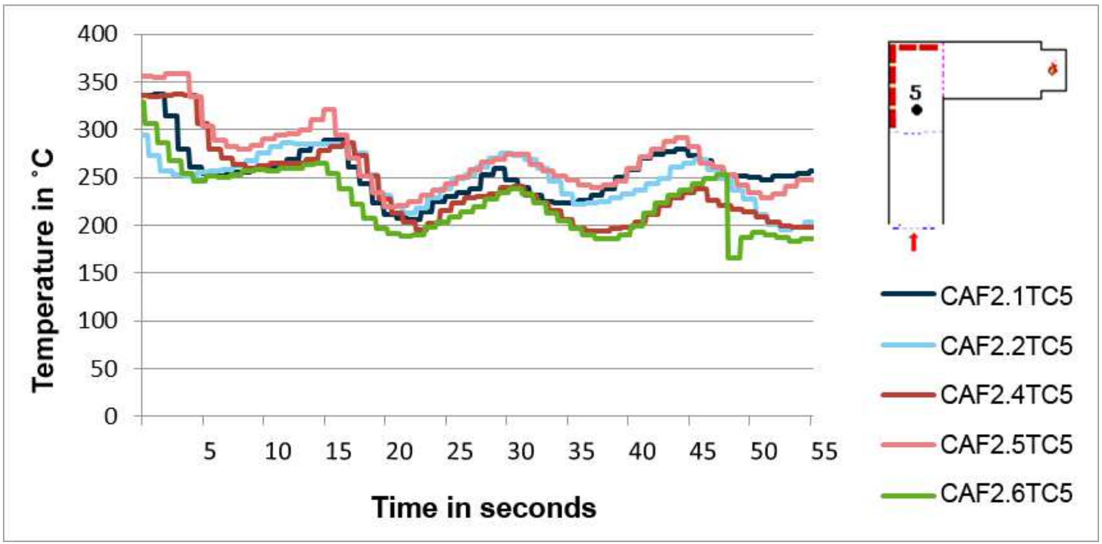

Figure 3.5. Reproducibility of CAF 2.0 experiments, fire gas cooling, thermocouple 5

Figure 3.5 shows that the temperature trend of the five experiments is comparable. The lines follow a comparable pattern. The experiments with CAF2.4 and CAF2.5 differ slightly because the attacks in these experiments after the first shot show an effect in the decrease in temperature a few seconds later than the other experiments. The maximum temperature variance in the pattern of the five experiments is 65 ˚C for the lowest values after the attacks. Experiment CAF2.6 shows a sudden decrease in temperature of some 80 ˚C at about 48 seconds. This was probably due to the thermocouple being hit during the attack. CAF2.3 is missing from the figure. This was due to the attack protocol not having been followed correctly during this attack. For this reason, an extra test was conducted (CAF2.6) to reach the number of five attacks again.

3.4 Conclusion about reproducibility

Since the result of the LP reference experiment matches the LP results from the previous experiments, it is assumed that the test conditions in the experiments of 2013 were comparable to those of the experiments with CAF 2.0 in 2014. This enables the results of the experiments with CAF 2.0 to be compared to the results of the previous experiments with CAF 1.0, LP and HP.
Furthermore, the starting temperatures show that there were no significant differences between the fire growths of the fires in the different experiments with the tactics.
The experiments with CAF 2.0 are comparable to such a degree that average values can be deduced from the measurements of the five individual experiments. The results of the experiments with CAF 1.0, LP and HP also show that the results of attacks per tactic are compatible with each other. This enables the average results of the four methods of attack to be compared.

4 Results of fire gas cooling

The sections below begin by going into the temperature trends during the two individual series of fire gas cooling applications in the room where the attack took place. After this, the temperature trend over the entire container during the entire attack of one minute in the centre of the container and in the rest of the container is considered. Where a comparison is made between CAF 2.0 and the previous experiments with LP, HP and CAF 1.0, a time of 55 seconds is assumed since this is the length of time used in the previous experiments.

4.1 Temperature trends of individual series of fire gas cooling applications

This section considers the temperature trends for the four systems studied during the individual series of fire gas cooling applications in the rooms that were the subject of the tests.
Since the first series of fire gas cooling applications was conducted from the entrance to the container, the temperature decrease on TC 1 until 25 seconds after the start of the experiment was considered for the first series of fire gas cooling applications (1-3). Since the second series of fire gas cooling applications was conducted halfway into the container, the temperature decrease on TC 5 from the first moment of the effect of the second series of fire gas cooling applications until 25 seconds after this moment was considered for the second series of fire gas cooling applications (4-6).[31]

4.1.1 First series of fire gas cooling applications (TC1)

Figure 4.1 shows the temperature trends for the first part of the fire gas cooling application (in the front part of the container, thermocouple 1).

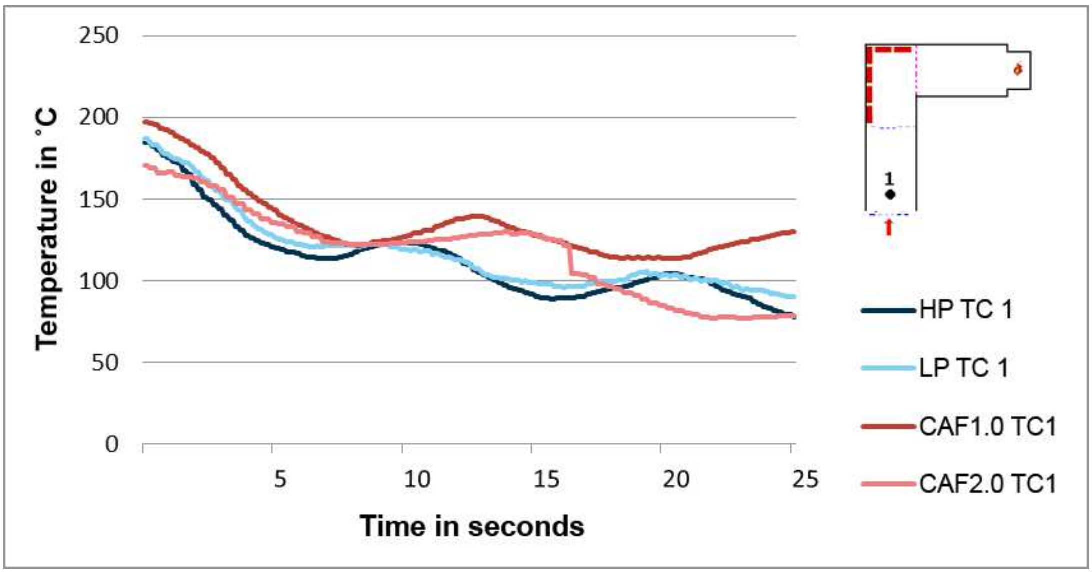

Figure 4.1. Temperature trends of first series (shots 1-3), average values per system, thermocouple 1

[31] Analogous with the report from 2013.

The starting temperature in the first part of the container (on TC1) was the highest with CAF 1.0 (T≈200 ˚C) and the lowest with CAF 2.0 (T≈170 ˚C). The first shot showed the strongest decrease in temperature for all the tactics. This decrease in temperature was the least for CAF 2.0; the other tactics showed a decrease of more or less the same extent. After this, all the curves show a wave pattern with the temperature decreasing immediately after a shot, to increase again after this. This increase is the greatest for CAF 1.0. Eventually, the decrease in temperature after 25 seconds is the strongest for HP (ΔT=106 ˚C), this is approximated by the effects with LP (ΔT=98 ˚C) and CAF 2.0 (ΔT=91 ˚C). The temperature dropped the least with CAF 1.0 (ΔT=66 ˚C). As a result of these decreases in temperature, the final temperature (measured at t=25) with CAF 2.0, HP and LP is at about 85 ˚C and with CAF 1.0 it is 130 ˚C.

The HP, LP and CAF 2.0 systems showed comparable effects in absolute decrease in temperature in the front part of the container, at the point where the attack crew first had to enter the room on fire. CAF 2.0 provided better cooling than CAF 1.0.

4.1.2 Second series of fire gas cooling applications (TC5)

Figure 4.2 shows the temperature trends in the centre of the container (thermocouple 5) during the second series of fire gas cooling applications for each system. The graph shows the times per system corrected on the basis of the observable effect of the second series of fire gas cooling applications, as a result of which the start of the second series of fire gas cooling applications for all systems has been synchronised at t = 30.[32]

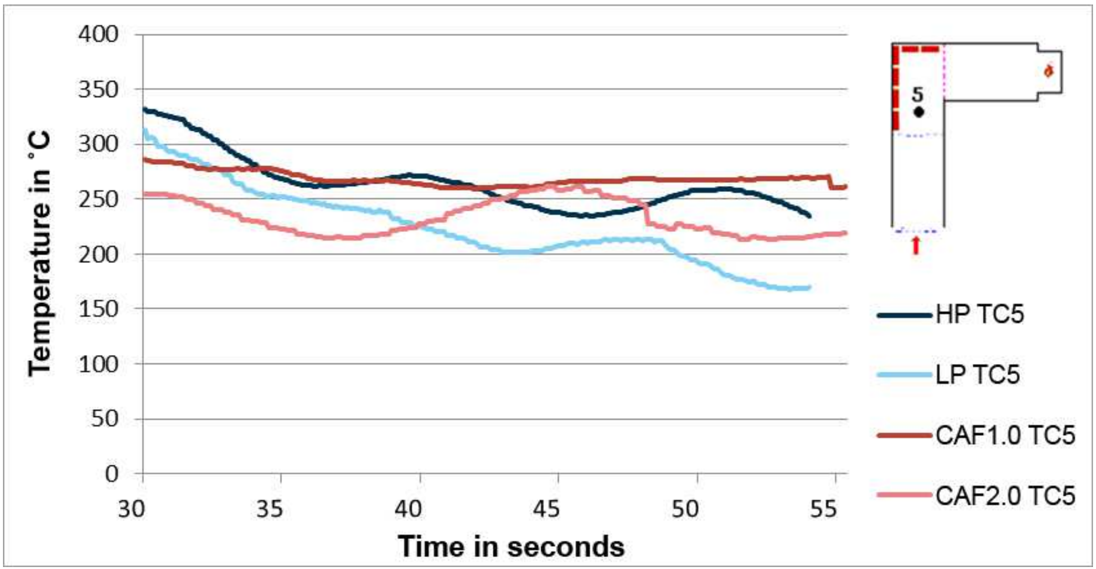

Figure 4.2. Temperature trends of second series (shots 4-6), average values per system, thermocouple 5

The starting temperatures were higher in this part of the container (TC5) than in the first part of the container (TC1). The starting temperature in the second part of the container was the highest with HP (T≈330 ˚C) and the lowest with CAF 2.0 (T≈255 ˚C). It must be noted here that, at that moment and as a result of the first series of fire gas cooling applications, the

[32] The fire gas cooling effect occured at different times for every individual system. Since the start of the effect with the different systems has been synchronized in figure 4.2, the significance of the effect for every individual system can be compared well to the significance of the effect of the other systems.

temperature on thermocouple 5 had already decreased by some 80 ˚C with CAF 2.0 and some 20 ˚C with CAF 1.0 and LP (see figure 4.9 later in this report).

A wave-shaped temperature curve can also be seen in the second series of fire gas cooling applications for all the systems tested, except CAF 1.0. The temperature increased again after the cooling effect. This increase was the greatest for CAF 2.0 and the smallest for LP and CAF 1.0. On the contrary, the second series of fire gas cooling applications with CAF 1.0 hardly showed a decrease in temperature either. The decrease in temperature (measured at t = 55) was 143 ˚C for LP, 97 ˚C for HP, 25 ˚C for CAF 1.0 and 35 ˚C for CAF 2.0.

The eventual effect on the absolute decrease in fire gas temperature was the greatest for LP. HP scored less well, but still better than CAF 2.0. CAF 1.0 provided the least cooling. It must be noted in this respect that, with CAF 2.0, the temperature had already decreased at the start of the second series of fire gas cooling applications.

When setting off the decreases in temperature on thermocouple 5 as a consequence of the second fire gas cooling application against the decreases in temperature as a consequence of the first fire gas cooling application on this thermocouple, it was found that the temperature dropped the most with LP (ΔT = 162 ˚C) and the least with CAF 1.0 (ΔT = 43 ˚C). The values for the decreases in temperature with CAF 2.0 (ΔT = 113 ˚C) and with HP (ΔT = 97 ˚C) were somewhere between these extremes. As a consequence of these decreases in temperature, the final temperature (measured at t = 55) was the lowest for LP (T≈170 ˚C) and the highest for CAF 1.0 (T≈270 ˚C).

4.2 Temperature trend in the entire container during the attack

The absolute[33] temperature trend in the entire container during the two series of fire gas cooling applications is analysed in this section. This enables statements to be made about the effect of an attack further in the room and behind the attack crew. Figure 4.3 shows the average temperature trends for the attack with CAF 2.0 at different positions in the test object (on the different thermocouples). To enable a comparison, the graphs of CAF 1.0, HP and LP are also shown.

One would expect to see an effect for the first series of fire gas cooling applications, specifically on thermocouple 1 (at the front near the door) and thermocouple 3 (halfway the first part of the compartment), and, for the second series of fire gas cooling applications, on thermocouple 5 (at the front in the second part of the compartment) and 7 (in the corner)[34]. Thermocouple 9 was located near the seat of the fire.

33 Absolute here means: the actual difference, regardless of the amount of extinguishing agent and/or water introduced. The relative cooling (per litre of water) is presented in section 4.3.

34 Due to its corner location, thermocouple 7 was not only heated by convection, but also by direct radiation from the seat of the fire.

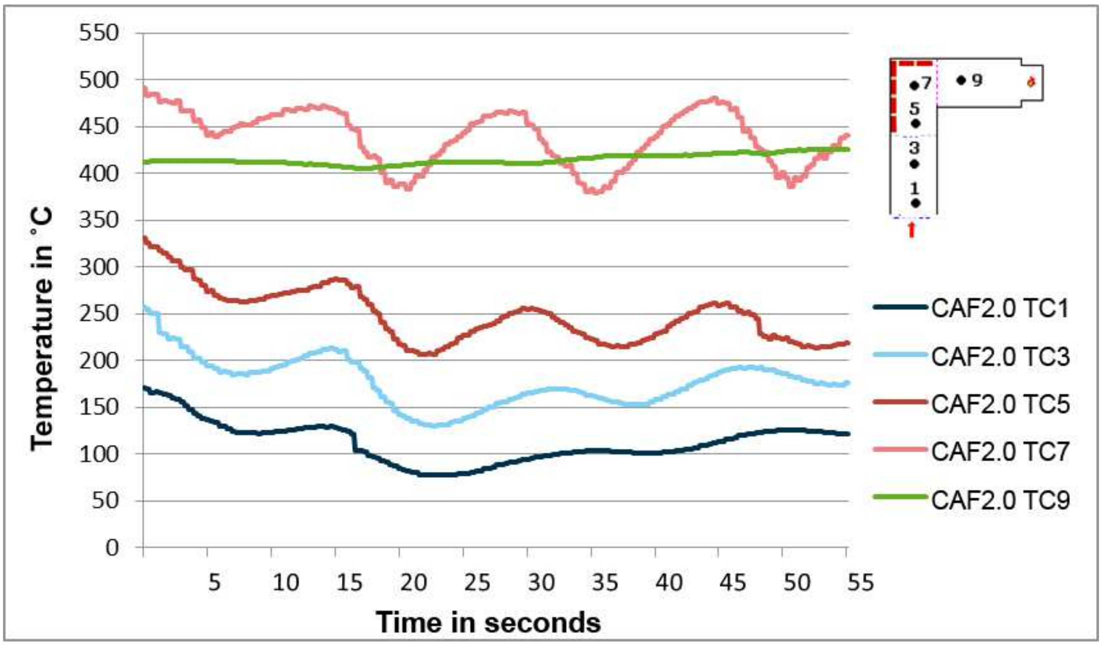

Figure 4.3. Temperature trends for CAF 2.0 fire gas cooling, average values per thermocouple (TC)

The attacks with CAF 2.0 showed a decrease in temperature on thermocouples 1 and 3 ($\Delta T_{CAF\ 2.0,TC1}$≈45 ˚C; $\Delta\ T_{CAF\ 2.0,TC3}$≈70 ˚C) immediately after the first shot. A decrease in temperature was also measured on thermocouples 5 and 7 ($\Delta T_{CAF\ 2.0,TC5}$≈70 ˚C; $\Delta\ T_{CAF\ 2.0,TC7}$≈50 ˚C), located further into the container. This temperature effect further into the container was not observed with the experiments with CAF 1.0, HP and LP (see also figures 4.4, 4.5 and 4.6).

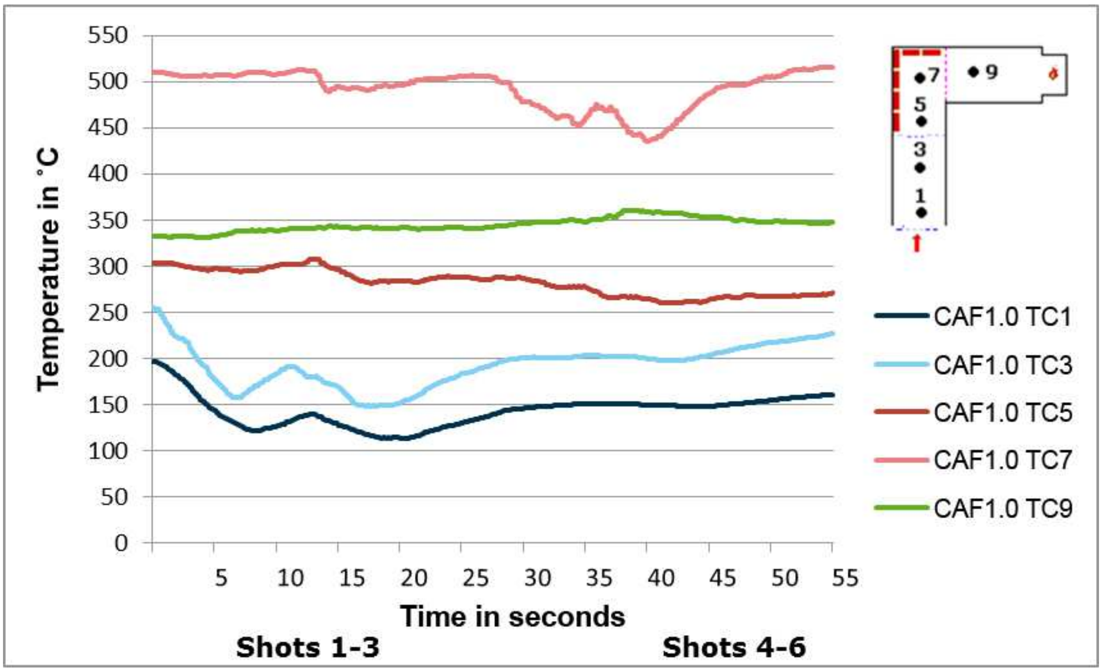

Figure 4.4 Temperature trends for CAF 1.0 fire gas cooling, average values per thermocouple (TC)

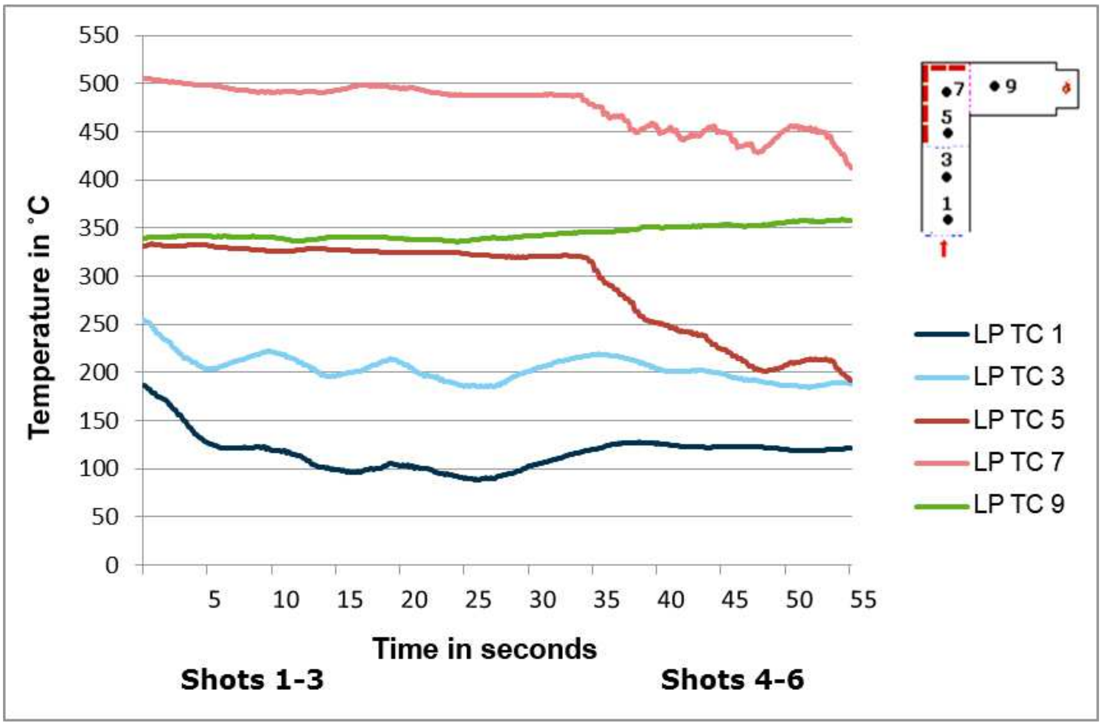

Figure 4.5. Temperature trends for LP fire gas cooling, average values per thermocouple (TC)

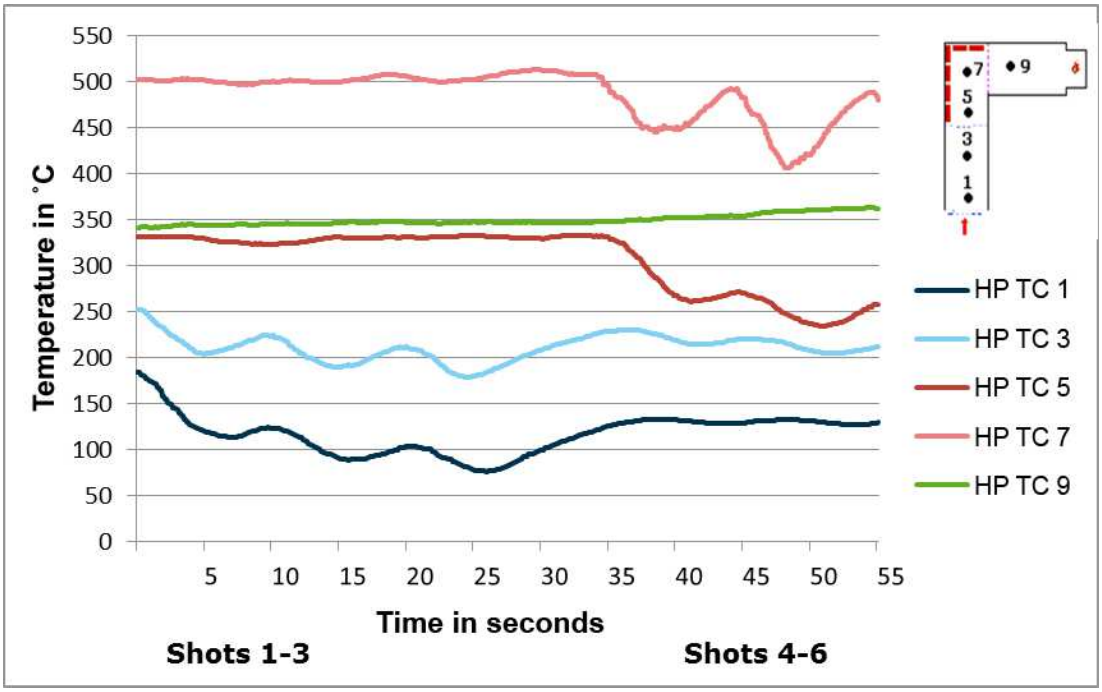

Figure 4.6. Temperature trends for HP fire gas cooling, average values per thermocouple (TC)

The following figures show graphs of the four systems per thermocouple.

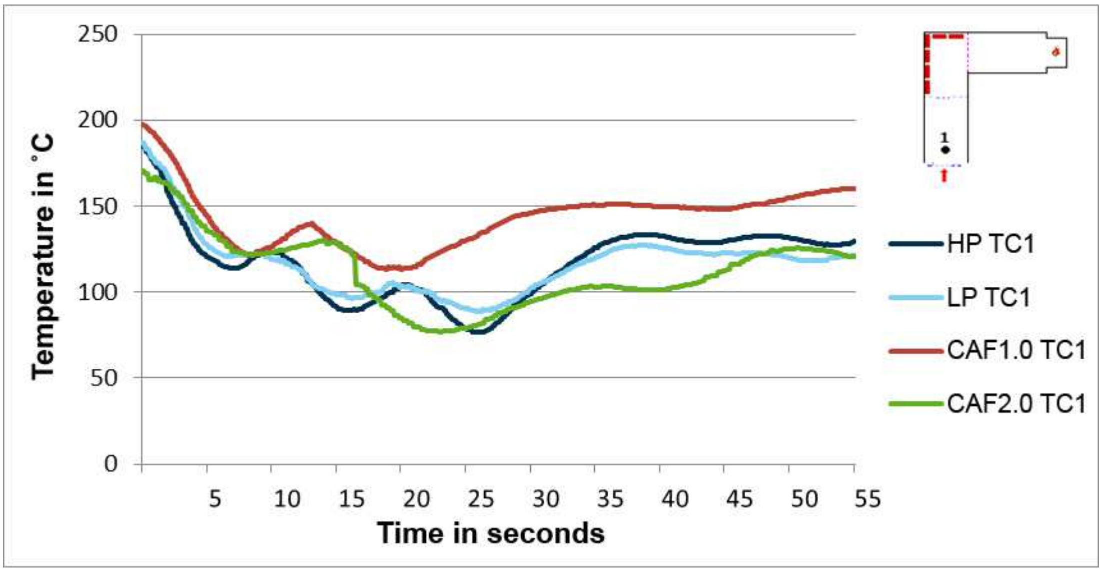

Figure 4.7. Temperature trends for fire gas cooling, average values per system on thermocouple 1 (TC1)

Please refer to section 4.1 for a description of the effect of the first series of fire gas cooling applications on thermocouple 1. Figure 4.7 shows that the temperature increased again for all four of the systems tested after the first series of fire gas cooling applications (i.e. while the crew was moving from the front door to the second positioning line). The final temperature (at t = 55) relative to the starting temperature had decreased the most for LP and the least for CAF 1.0 (ΔT_{LP}=64 °C; ΔT_{HP}=58 °C; $\Delta T_{CAF\ 2.0}$=49 °C; $\Delta T_{CAF\ 1.0}$=40 °C).

The absolute decrease in temperature on thermocouple 1 at the front of the container is comparable for HP, LP and CAF 2.0.

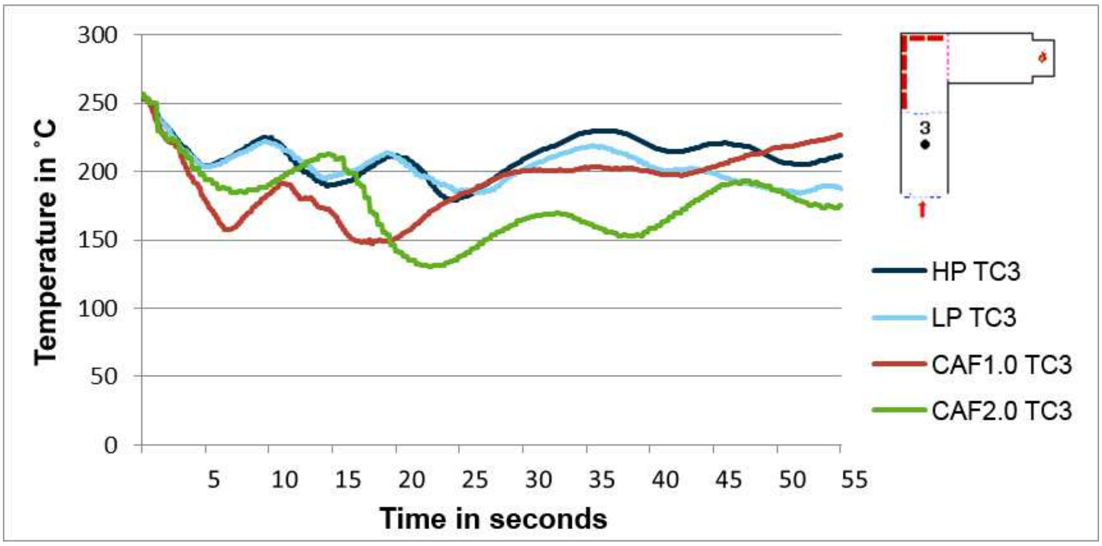

Figure 4.8. Temperature trends for fire gas cooling, average values per system on thermocouple 3 (TC3)

Figure 4.8 shows that, after the first series of fire gas cooling applications, the temperature on thermocouple 3 dropped significantly with CAF 2.0 and CAF 1.0 ($\Delta T_{CAF\ 2.0}$=122 °C; $\Delta T_{CAF\ 1.0}$=106 °C). The temperature also decreased with HP and LP, but not as much as with CAF 1.0 and 2.0 (ΔT_{LP}=64 °C; ΔT_{HP}=75 °C). The temperature increased again with all four of the systems tested after the first series of fire gas cooling applications. Just before the second series of fire gas cooling applications, the peak temperature at the line where the attack crew positioned itself was the lowest with CAF 2.0 and the highest with HP ($\Delta T_{CAF\ 2.0}$=166 °C; $\Delta T_{CAF\ 1.0}$=201 °C; ΔT_{LP}=219 °C; ΔT_{HP}=229 °C). As a consequence of the second series of fire gas cooling applications, the temperature decreased slightly again from t=35 for HP and LP, whereas the temperature at the line where the attack crew positioned itself increased slightly for CAF1.0 ($\Delta T_{CAF\ 1.0}$≈20 ˚C) and CAF 2.0 showed a wave pattern with a limited increase between t=35 and t=45 ($\Delta T_{CAF\ 2.0}$≈35 ˚C). The eventual decrease in temperature at t = 55 was the most significant for CAF 2.0 and the least significant for CAF 1.0 ($\Delta T_{CAF\ 2.0}$=80 °C; ΔT_{LP}=66 °C; ΔT_{HP}=44 °C; $\Delta T_{CAF\ 1.0}$=29 °C).

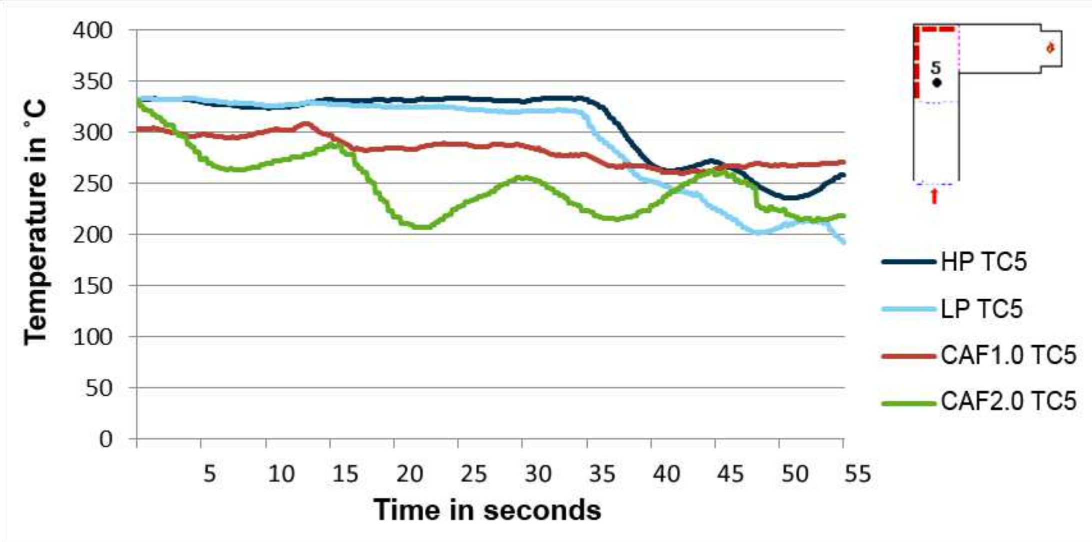

Figure 4.9. Temperature trends for fire gas cooling, average values per system on thermocouple 5 (TC5)

Contrary to CAF 1.0, HP and LP, CAF 2.0 produced a decrease in temperature on thermocouple 5 from the first shot. These latter tactics did not have an effect on thermocouple 5 until the second part of the attack. That can be explained by the fact that the application of CAF 2.0 was started at the door opening and the throw length reached as far as the second part of the container. The attack with CAF 1.0 started outside, at seven metres from the entrance and, as a result, did not reach that far. As the throw lengths of LP and HP are less, they failed to reach thermocouple 5 during the first shots. The temperature curves of HP and LP showed a decrease in temperature in the second series of fire gas cooling applications; here the decrease in temperature was the greatest for LP. In this phase, the temperature fluctuated at about 225 °C, within a range of approx. 50 °C for CAF 2.0. For CAF 1.0, the temperature remained constant at about 265 °C in the second series of fire gas cooling applications. In the end, the temperature (measured at t = 55) had decreased the most for LP and it had decreased the least for CAF 1.0 (ΔT_{LP}=138 °C; $\Delta T_{CAF\ 2.0}$=112°C; ΔT_{HP}=73 °C; $\Delta T_{CAF\ 1.0}$=41 °C).

CAF 2.0 led to the greatest absolute decrease on thermocouple 5 for the first series of fire gas cooling applications. Its further decrease was limited with the second series of fire gas cooling applications, whereas LP and HP showed a decrease. In the end, LP showed the greatest absolute cooling capacity, followed by CAF 2.0, HP and CAF 1.0.

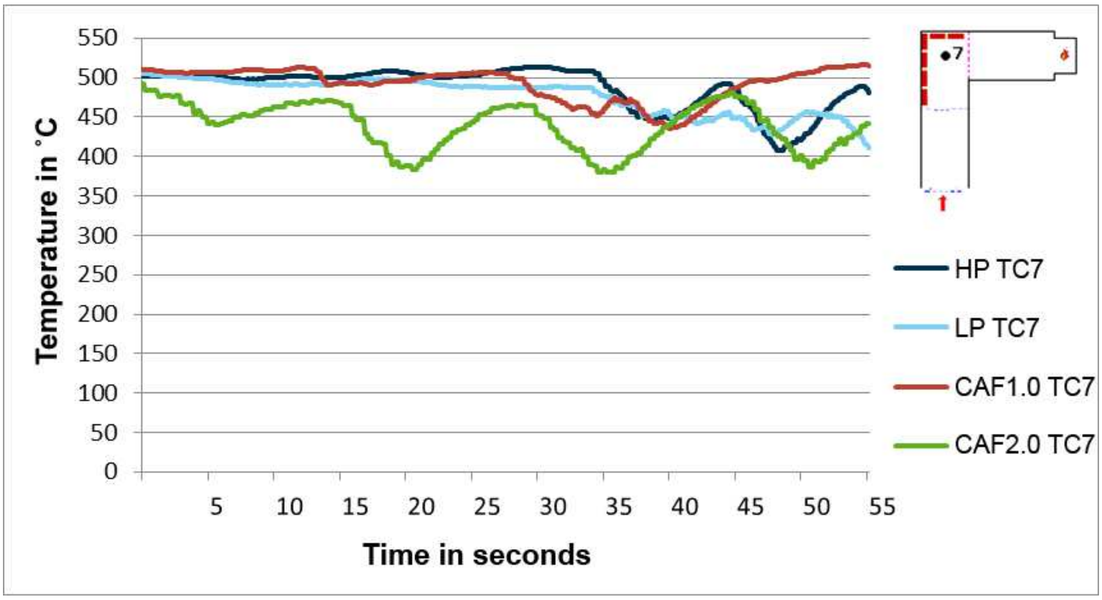

Figure 4.10. Temperature trends for fire gas cooling, average values per system on thermocouple 7 (TC7)

CAF 2.0 also showed a decrease in temperature in the first series of fire gas applications on thermocouple 7, whereas this was not the case with the other systems tested. CAF 2.0 showed a strong wave-patterned movement throughout the test period, revealing that the temperature decreased after every shot to increase again afterwards. During the fire gas cooling applications with CAF 2.0, the temperature fluctuated at around 435 °C, within a range of approx. 100 °C. HP also showed a strong wave movement in the second series of fire gas cooling applications, with the temperature eventually fluctuating at about 450 °C, within a range of approx. 100 °C. The eventual temperature with CAF 1.0 was even slightly higher than the initial temperature. Only LP managed to achieve a more stable decrease in temperature on thermocouple 7 (especially from t=35) and reached the greatest decrease in temperature of the four systems tested (ΔT_{LP}=91 °C) at t = 55.

CAF 2.0 produced a stronger decrease in temperature than the other systems with the first series of fire gas cooling applications at the back of the container on thermocouple 7. During the series of cooling applications in the container itself, only LP was capable of achieving a structurally decreasing temperature line.

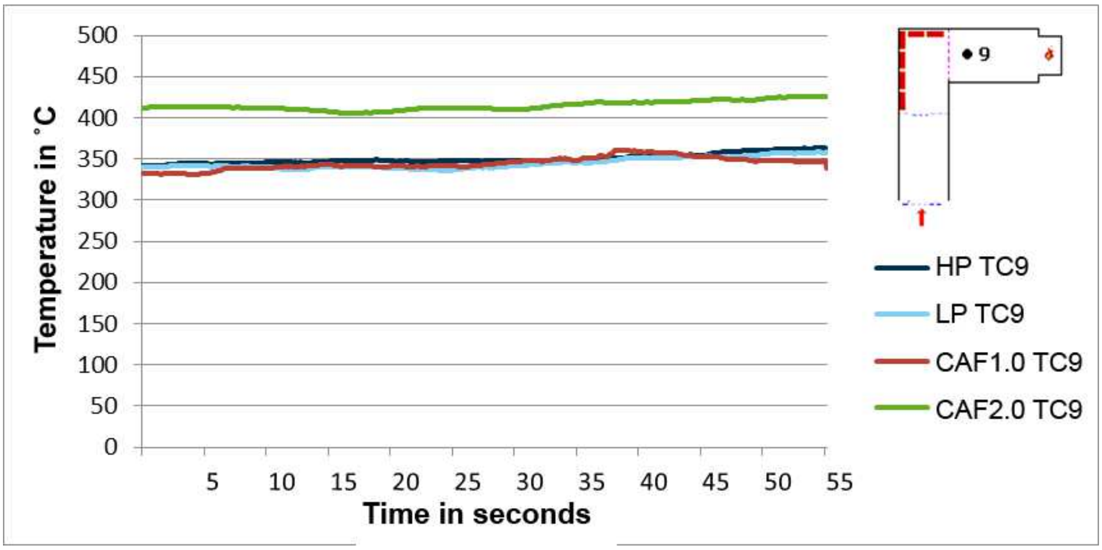

Figure 4.11. Temperature trends for fire gas cooling, average values per system on thermocouple 9 (TC9)

All systems showed a higher final temperature on thermocouple 9 than the temperature at the start of the experiment. No differences were visible between the systems.

Table 4.1 shows a summary of the temperature differences of all thermocouples located against the ceiling of the container. The table shows the difference between the temperature at the start of the experiment, and at the end, at t = 55 seconds.

Table 4.1. Summary of ∑Δtemp of all the thermocouples at t = 55

TC	CAF 2.0	CAF 1.0	LP	HP
1	-50	-38	-65	-54
3	-78	-32	-71	-38
5	-107	-42	-150	-72
7	-36	+5	-112	-52
9	+13	+8	+19	+19
Total (∑Δtemp)	-258	-99	-379	-197

The above table confirms what was found on thermocouple 5: LP cools the best from an absolute point of view, followed by CAF 2.0, and then HP and finally CAF 1.0.

4.3 Water usage in relation to fire gas cooling

The cooling capacity depends on the amount of water introduced that can evaporate. The following is true in principle: the more water, the more cooling. The previous sections considered the absolute decrease in temperature. However, different amounts of water/extinguishant were introduced for the different tests of the different tactics. To enable a good comparison as regards effectiveness, the relative cooling value per litre of water has also been included. The water usage during the entire attack has been related to the total decrease in temperature on thermocouple 5.
During the experiments, the water usage was measured using a water meter. A digital water meter was used for the tests with CAF 2.0. An analogue water meter was used for the previous tests with HP, LP and CAF 1.0[35]. To make sure that the water measurements conducted during the experiments with CAF 1.0 and 2.0 are correct, some comparison tests were conducted. And furthermore Kiwa, being an expert in this field, was asked if the water meters are reliable and if the way in which the meters were used is correct. The results, the analysis and the conclusion of the comparison tests can be found in annex 2 and the study by Kiwa in annex 3.
Based on the comparison tests and the study by Kiwa, it was concluded that the results of the measurements, and the results to be expected, given the error margin, do not conflict with each other. Therefore, it can be assumed that the measurements and the results are correct and that the results of the water measurements of the experiments with LP, HP and

35 The water went from the hydrant through the water meter and bypassed the tank. The water meter readings were recorded after every series of fire gas cooling applications.

CAF 1.0 and those of the experiments with CAF 2.0 can be compared to each other.

Table 4.2. Average water usage during the fire gas cooling experiments on thermocouple 5

Tactic	Measured amount of water introduced, in litres	Standard deviation	Decrease in temperature of total fire gas cooling on TC 5	Decrease in temperature in degrees per litre of water
CAF 1.0	29	8.8	41	1.4
CAF 2.0	74	7.4	112	1.5
Low pressure	42	6.6	152	3.6
High pressure	32	3.5	73	2.3

Table 4.2 shows that if the decrease in temperature is related to the amount of water introduced, the fire gas cooling capacity of LP is the greatest (3.6 ˚C/l), followed by HP (2.3 ˚C/l), CAF 2.0 (1.5 ˚C/l) and CAF 1.0 (1.4 ˚C/l).

The above calculation was based on thermocouple 5. Since CAF 2.0 already had an effect further into the room at an early stage, the total cooling on all the thermocouples was related to the water usage for the sake of completeness. See table 4.3 for this.

Table 4.3. Average water usage during fire gas cooling on all thermocouples

Tactic	Measured amount of water introduced, in litres	Standard deviation	∑Δtemp of all thermocouples	Decrease in temperature in degrees per litre of water
CAF 1.0	29	8.8	-99	3.4
CAF 2.0	74	7.4	-258	3.5
Low pressure	42	6.6	-379	9.0
High pressure	32	3.5	-197	6.2

Table 4.3 shows that, if the decrease in temperature on all thermocouples is related to the amount of water introduced, the fire gas cooling capacity of LP is the greatest (9ºC/l), followed by 6.2 °C/l for HP, and then CAF 2.0 (3.5 ºC/l) and finally CAF 1.0 (3.4 ºC/ltr).

LP is the most effective as regards its fire gas cooling effect per litre of water introduced, followed by HP and then CAF 2.0. CAF 1.0 scores the lowest as regards its cooling capacity per litre of water.

Since CAF uses a foam-forming agent and air to convert water into foam, the expansion rate of the One Seven® that was subject of the study was determined during the tests with CAF

2.0. This was 8.7 on average.[36] This means that, for CAF 2.0, one litre of water introduced equals 8.7 litres of foam.

4.4 Other findings

An increase in temperature was detected while testing using CAF 1.0, as well as combustion of the layer of fire gas. The report *Cooling experiments with water and foam* (2013) contained the conclusion that this may lead to hazardous situations for firefighters in a real-life fire situation. These phenomena were not observed in the tests with application method CAS 2.0.

[36] Test 1: 8; test 2: 8.35; test 3: 9.1; test 4: 8.8; test 5: 9.2. These measurements were conducted by One Seven® of Germany. Since these values were not determined in the previous experiments, a comparison to the previous study is not possible.

5 Conclusion, interpretation and recommendations

5.1 Conclusion

This section answers the research question as posed in the introduction.

How does the effectiveness of CAF 2.0, as regards the fire gas cooling effect during an offensive indoor attack in response to a simulated fire in a living room, compare to that of low pressure (LP), high pressure (HP) and CAF 1.0?

In an absolute sense, LP produced the greatest decrease in temperature when considering the total fire gas cooling process. CAF 2.0 scored better than HP. CAF 1.0 produced the least fire gas cooling during the total attack. This was both true for the cooling effect measured on the reference thermocouple 5, and the aggregated cooling effects measured on all the thermocouples present.
The decrease in temperature using CAF 2.0 has been found to vary depending on the actual location of attack. When attacking the *front* part of the container, the absolute effect in the decrease in temperature of CAF 2.0 was comparable to that of HP. All three of the systems were found to be capable of cooling fire gases to a more or less equal degree when used in the part of the room during an attack from outside. CAF 2.0 gave a better cooling effect in the front part of the room than CAF 1.0. During the first series of fire gas cooling applications, CAF 2.0 reached a greater decrease in temperature *halfway* into the container than LP, HP and CAF 1.0.
Contrary to the other systems, the One Seven® studied for CAF 2.0 had already achieved a decrease in temperature *in the rear of* the container during the first series of fire gas cooling applications. This means that the attack with CAF 2.0 had a greater effect further into the room. During the second series of fire gas cooling applications, during an attack halfway into the container, the further effect of CAF 2.0 was limited, whereas LP and HP showed a decrease. As a result, the total fire gas cooling as an *absolute* decrease in temperature when using CAF 2.0 was less than when using LP, but it was better than the result achieved when using HP or CAF 1.0.

Different amounts of water were introduced while testing, depending on the tactic and the application method. Therefore, the cooling achieved is related to the water usage, which then leads to a statement about the effectiveness per litre of water introduced.[37] When compared to the amount of water introduced, LP is found to be the most effective, giving a 3.6 ˚C decrease per litre of water introduced. This is followed by 2.3 ˚C per litre for HP, 1.5 ˚C per litre for CAF 2.0 and 1.4 ˚C per litre for CAF 1.0.[38]

The above results lead to the conclusion that fire gas cooling using CAF according to method 2.0 is possible and that this yields better results than CAF 1.0. The added value of

37 The calculations were based on the total amount of water introduced. This attack has the possibility of not all the water that is introduced contributing to this cooling, e.g. because it falls on the floor.

38 CAF uses a foam-forming concentrate and air to convert the water into foam, enabling one litre of water to be converted into 8.7 litres of foam when using the CAF One Seven® studied (based on the average expansion rate during the experiments with CAF 2.0).

CAF 2.0 is mainly its cooling effect further into in the container, when used as part of the attack in the first series of fire gas cooling applications. The further cooling effect is found to be limited in the second series of fire gas cooling applications halfway into the container. This shows that fire gas cooling using CAF 2.0 is possible, as stated above.
This means that, when related to the number of litres of water, CAF 2.0 cools slightly better than CAF 1.0, but the fire gas cooling by CAF 2.0 per litre of water introduced is less effective than it would have been if LP or HP had been used.

An increase in temperature was detected while testing using CAF 1.0, as well as combustion of the layer of fire gas. These phenomena were not observed in the tests with application method CAS 2.0.

5.2 Interpretation and recommendations

It is again emphasized that the results and conclusions found only apply exclusively to the method of attack and test circumstances described in this study. Other application tactics or circumstances may lead to other results[39].
Only statements about the effectiveness of fire gas cooling can be based on this report. No other pre-supposed advantages or disadvantages of CAF compared to water have been studied.

When interpreting the results, it is important to realise that, when carrying out an attack, there is a possibility that not all the water that has been introduced contributes to this cooling before, for example, falling on the floor. This is true for all systems tested.

The analysis of the experiments shows that the method used with CAF 2.0 leads to better results than the method used with CAF 1.0. Since the method used with CAF 1.0 is actually used by some of the fire brigades in the Netherlands, it is our recommendation that the brigades that use the CAF system are well aware of the correct use of this system. It is important that sufficient extinguishant is introduced.

The experiments also showed that the temperature will increase again if fire gas cooling is stopped before the seat of the fire is attacked. This is logical because the 'engine' for the fire gas production is not stopped. This means that, both with water and with CAF, continual cooling from the moment of entering the room is required until the seat of the fire can be reached and fully put out. For LP and HP, this means introducing water into the layer of fire gas and for CAF this means that foam must be applied to all the walls and ceilings. Using the throw length is important.

[39] As stated above, One Seven® was the only compressed air foam system used for testing as part of this study. Users of other systems are recommended to contact their suppliers for further information about whether these systems can or cannot be used for putting out fires inside buildings.

Annex 1: Fire extinguishing

Introduction into fire extinguishing using CAF 2.0

As the actual extinguishing of the fire was not part of the comparative study, a practical approach to putting out the seat of the fire was selected in consultation with the supplier of One Seven®. The fire extinguishing method selected differed from the previously conducted experiments with CAF 1.0, HP and LP. In the previous experiments, the fire was extinguished until there was a visual knockdown[40]. The attack crew then waited for the fire to flare up again[41] and then they extinguished it again. This was repeated a couple of times.
As part of the study into CAF 2.0, One Seven® was used to extinguish the fire until the firefighting crew indicated that it had been extinguished sufficiently. The crew then waited for the fire to flare up again. If it did, the extinguishing was repeated until the fire fighting crew indicated that it had been extinguished sufficiently far. This different setup makes it impossible to make comparisons and to draw conclusions about the fire extinguishing effects. Therefore, this annex only presents a description of the facts.
The technicalities of the extinguishing of the fire were as follows: After the fire gas cooling, the crew members stationed themselves near the short side of the container (the pink line in figure B1 in the direction of the seat of the fire). Twenty seconds after the end of the fire gas cooling effort, the team was given the command to ‘extinguish’ the fire. When testing CAF 2.0, the fire was extinguished by applying One Seven® foam to the surroundings of the seat of the fire, and eventually the seat of the fire itself by means of a rotary movement. When an attempt to put out the fire had ended, the crew waited to see if the fire flared up again. If the fire did flare up again, the crew would wait for another 10 seconds to extinguish the fire again until the nozzle operator thought the fire had been put out completely.

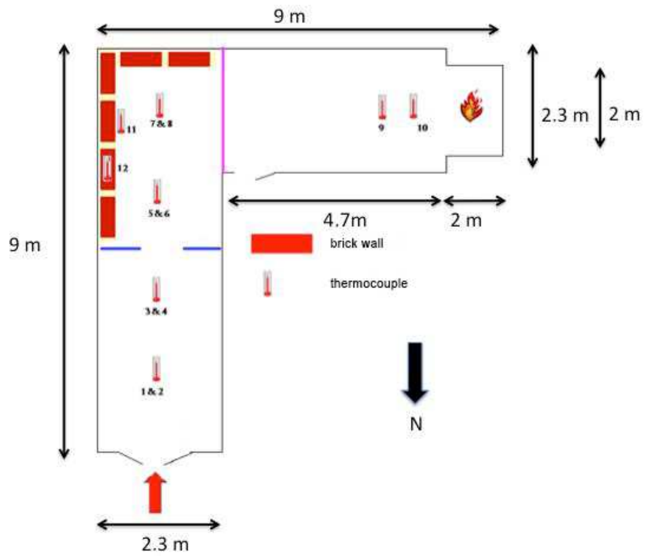

Figure B1. Pink positioning line for extinguishing the fire

40 Flames no longer being visible.
41 For the sake of the study, extinguishing the fire was stopped to study its effect, in other words if and when it flared up again. This was the consequence of a choice made for the setup of the test and it is not something that will always take place in a real attack.

Temperature trends during fire extinguishing

The temperature trends during fire extinguishing on thermocouple 10 (the one nearest to the site of the fire) are shown in figure B2.

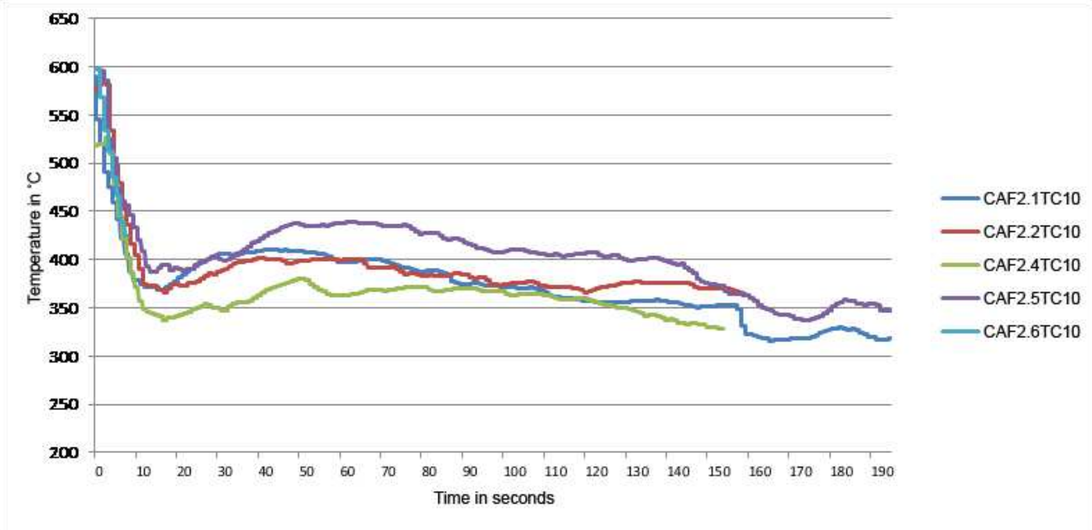

Figure B2. Temperature trends during fire extinguishing using CAF 2.0, thermocouple 10

Figure B2 shows that, when testing using CAF 2.0, the extinguishing team thought that the fire had been extinguished sufficiently far after approx. 15 seconds (the strong decrease in temperature stopped then) and that the temperature had dropped on average by approx. 198˚C (SD = 21.0) ($\Delta T_{CAF2.1,kd1}$= 221 ˚C; $\Delta T_{CAF2.2,kd1}$= 212 ˚C; $\Delta T_{CAF2.4,kd1}$= 176 ˚C; $\Delta T_{CAF2.5,kd1}$= 206 ˚C; $\Delta T_{CAF2.6,kd1}$= 176 ˚C[42]).

Temperature trends in the entire container during fire extinguishing

While extinguishing the fire, the fire crew was located in the rear part of the container (between thermocouples 7 and 9). To get an idea of the effect of the fire extinguishing action on the temperature trends *behind* the fire crew, this section shows the measurements on thermocouples 1-3-5-7-9-10 while the fire was being extinguished.

[42] The measurement was stopped after 8 seconds in experiment 2.6.

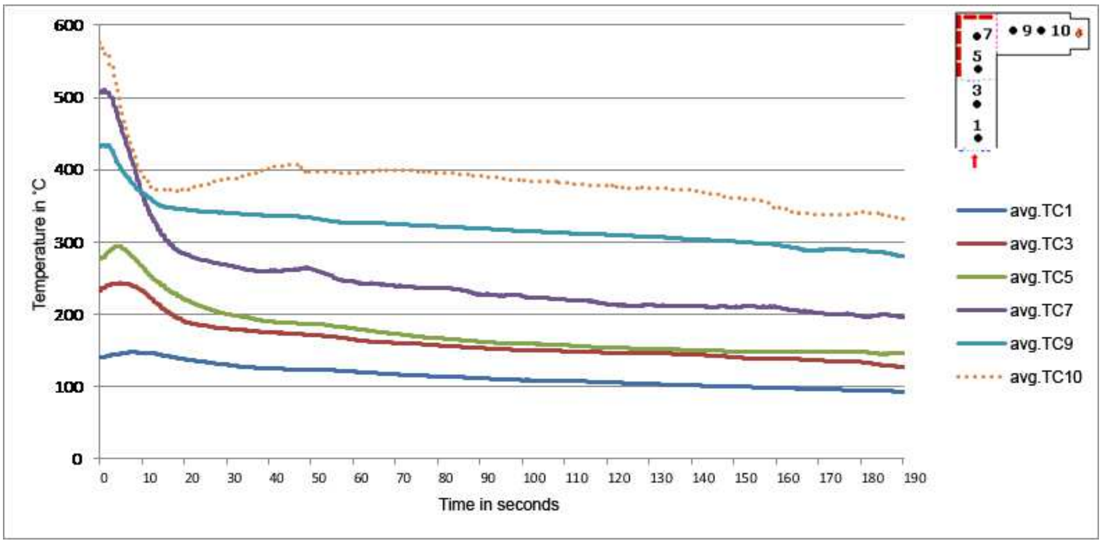

Figure B3. Temperature trends for fire extinguishing using CAF 2.0, average values per thermocouple (TC)

The above graph shows that, while the fire was being extinguished using CAF 2.0, a permanently decreasing line could be observed in the temperature in the container, after the temperature had first dropped severely due to the cooling effect of the fire extinguishing action. This means that the temperature behind the fire crew dropped slightly and did not increase while extinguishing the fire.

Water usage for fire extinguishing

The average amount of water used for extinguishing the fire was 73 litres (65-81 litres) (stdev=29.1). This matches approx. 634 litres of foam (based on the average expansion rate of 8.69 as applicable to One Seven®).

Annex 2: Water usage/water measurements

B 2.1 Introduction

As explained in section 2.2.3, the amount of water per series of fire gas cooling applications was measured during the experiments with HP, LP, CAF 1.0 and CAF 2.0. The water usage was measured using an analogue (mechanical) water meter for the HP, LP and CAF 1.0 experiments and a digital water meter (magnetically inductive flow meter) for the CAF 2.0 experiments.

After the experiments with CAF 2.0, the supplier had some questions as to the correctness of the water measurements.

This concerns the average water usage of 74 litres (with 4 shots) for fire gas cooling with CAF 2.0 (with five tests) as measured using the digital water meter. This was measured by first conducting the test from the filled tank and replenishing the tank afterwards. The digital water meter was located between the hydrant and the fire appliance.
The analogue water meter was used for the tests with CAF 1.0, LP and HP; here the meter was also located between the hydrant and the appliance. The water came from a source other than the tank; an observer recorded the water readings on the analogue water meter during the tests. The average water usage during the fire gas cooling for the tests with CAF 1.0 was 29 litres.

This means that the absolute water usage was measured during the experiments.

B 2.2 Conversion factors

Firstly, it should be noted that the goal and the intent of the experiments was to relate the absolute water usage against the decrease in temperature, and not to determine the flow rate (the water usage per minute). Water meters were used for this purpose. A water meter is a volume meter, not a flow meter.

The attack method of continuous pulses of 3 to 5 seconds, with foam being applied to the walls and ceilings, as advised by the supplier and the producer of One Seven®, was used for the CAF 2.0 experiments. The time observer, present at a distance, used a stopwatch and was in contact with the jet nozzle operator through a walkie-talkie. A 5-second pulse was approximated in this way.

There are considerable deviations as regards the unit of the 5-second pulse. Given the time it would take the jet nozzle operator and the time observer to react (a reaction time of 1 second can be assumed both when opening and when closing the jet nozzle), a shot can have been between 3 and 7 seconds (i.e. a difference of more than 1:2). This deviation/margin is probably even more significant, not only due to human deviations in the length of time, but also due to mechanical deviations (such as the check valve of the fire appliance and its reaction time). This means that the time was not exactly five seconds, mainly due to the communication and the manner in which the jet nozzle was closed (a fanshaped movement was made during the attack and this may have affected the speed of closing the jet nozzle).

Table 4.2 shows that the average amount of water in litres measured with CAF 2.0 (in 4 shots) for over five tests was 74 litres. 74 litres per 4 shots of 3 seconds (i.e. 12 seconds in total) means a flow rate of 370 l/min, whereas 74 litres per 4 shots of 7 seconds (i.e. a total of 28 seconds) means a flow rate of 159 l/min.

B 2.3 Maximum flow rate and (absolute) water measurements

The questions asked by the supplier and the manufacturer of One Seven® can be traced back to the assumption that the maximum flow rate of the mixer that is part of the One Seven® system is 135 l/min. Further studies have shown that this maximum flow rate is not correct when assuming shots of exactly 5 seconds. Furthermore, a study proved that the absolute water measurements conducted fall within the scope of the inaccuracy of the meter expected and are, therefore, reliable.

Further to questions asked by the supplier and the manufacturer of One Seven®, four tests were carried out in order to be able to determine whether the results of the water measurements are reliable. Those tests took place on 12 May 2014 (1), 16 May 2014 (2), 21 November 2014 (3) and 1 December 2014 (4). Besides this, Kiwa conducted an independent study (5).

B. 2.3.1 Test 1: 12 May 2014

Test setup
The first tests were conducted on the premises of the supplier of the One Seven® system on 12 May 2014. Those tests compared measurements of the digital water meter (CAF 2.0) and the analogue water meter (CAF 1.0) used during the two studies to measurements of two water meters used by the supplier (i.e. weighing platforms[43] and a digital water meter, calibrated according to the supplier, which were both made available by the supplier)[44].

For this purpose, the same fire appliance was used as in the tests with CAF 2.0.

Five tests were conducted. Contrary to the actual tests, the fire appliance was connected to a water mains in the premises (a 28mm water pipe) instead of to the underground fire hydrant (diameter of 160 mm) that was used with the experiments.

The water usage was determined during pulses of four times approx. five seconds (in accordance with the fire gas cooling experiments that had been carried out), however not in a container, and not in combination with breathing apparatus, walkie-talkies and a time observer present at a distance. This time, the time observer, with a stop watch, was in direct contact with, and positioned next to, the jet nozzle operator. The water usage was determined in retrospect.

[43] The sensitivity of the weighing platforms (how accurately they have been calibrated) is not known. The meter readout is indicated in increments of 5 kg: measuring per kg is not possible; only measuring in steps of 5 kg (i.e. 45-50-55 kg etc.) is possible. The error margin of the weighing platforms is unknown as well.
[44] It is also unknown how accurately this meter had been calibrated and what its error margin was.

Test results
These measurements showed that the amount of water used after four shots of approx. five seconds indicated by the digital water meter approximated the results of the digital water meter during the experiments with CAF 2.0. An average water usage of 74 litres during the experiments was measured by the digital water meter. On 12 May, five tests carried out using the digital water meter measured an average of 70.3 litres of water per series of four shots of approx. five seconds, i.e. a deviation of 5%.

Furthermore, the tests revealed that there was a difference between the digital meter on the one hand, and the measurements using the analogue meter (an average of 64.7 litres), the meter of the supplier[45] of One Seven® (an average of 55 litres) and the measurement by weighing (an average of 58 litres) on the other. There was no good explanation for these differences (although the sensitivity of the weighing platforms can largely explain the differences found relative to the weighing).

Regardless of the water meter or weighing platform used, these tests showed that the usage expressed in litres of water per minute when applying four shots of approx. five seconds is higher than the maximum limit of 135 l/min assumed by the manufacturer and supplier of One Seven®.

When assuming a time unit of approx. 20 seconds (four shots of approx. five seconds each), and converting this into a usage rate per minute, the values found are 165 l/min for the digital water meter used by the supplier of One Seven®, 174 l/min for the weighing platform of the supplier of One Seven®) 194 l/min for IFV's analogue water meter, and 211 l/min for IFV's digital water meter. The value measured by all the meters was higher than the maximum limit indicated.

Given the deviations in the length of time mentioned above, as a result of which the measurements varied from 12 seconds (4 shots of 3 seconds) to 28 seconds (4 shots of 7 seconds), this results in the following flow rates for the different meters as listed above: 252 l/min to 150 l/min, 323.5 l/min to 138 l/min, 275 l/min to 117 l/min, 290 l/min to 124 l/min.

Given the finding above, i.e. that 74 litres per 4 shots as measured during the CAF 2.0 experiments may have been applied in a time of 12 (4 shots of 3 seconds) to 28 seconds (4 shots of 7 seconds) which would result in a flow rate of 370 l/min to 159 l/min, this is a flow rate that is possible according to the various measurements.

In order to find out whether this can be explained from the use of shots instead of keeping the jet continuously open, 1-minute measurements using a continuously opened jet nozzle were also carried out. Here, the actual water usage was considerably lower (and less than the maximum limit assumed at 135 l/min), i.e. 102 l/min (digital water meter of the supplier of One Seven®), 104 l/min (digital weighing platform of the supplier of One Seven®), 112 (IFV's analogue water meter) and 122.5 litres (IFV's digital water meter).

The results of the 1-minute measurements confirm that the error margin in the time measurement in the study method used (shots of approx. 5 seconds) is considerable.

The differences between the different meters are also less for those 1-minute measurements. The difference between the meter that indicated the lowest water usage (102 litres) and the one that indicated the highest water usage (122.5 litres) is 20%. Since

45 Contrary to the other meters, this meter was not located at the inlet opening of the tank, but at the outlet opening.

those differences could not be fully explained yet, Kiwa was asked to conduct an independent study (see below).

B 2.3.2 Test 2: Own study by the supplier of One Seven® on 16 May 2014

The supplier also conducted measurements on its own premises, using its own meters and its own test setup. No IFV researchers attended these measurements or were involved in them.[46] Here, pulses of four times approx. five seconds were also used, after which the water usage was measured and weighed. This test also showed that the water usage (converted into litres per minute) was well above the limit of 135 l/min as indicated by the supplier when applying shots. Furthermore, the usage varied both as regards the method and the meters. According to the supplier of One Seven®, the values measured were as follows:

Meter used	Duration of use	Average result	Litres/min
Supplier's digital water meter	20 seconds (4x 5 sec)	55 litres (1st series) 54.8 litres (2nd series)	165 l/min (1st series) 164 l/min (2nd series)
Digital weighing by supplier	20 seconds (4x 5 sec)	60.8 litres (1st series) 56.3 litres (2nd series)	182 l/min (1st series) 169 l/min (2nd series)
Supplier's digital water meter	1 minute continuously	106 litres (1st series) 109 litres (2nd series)	106 l/min (1st series) 109 l/min (2nd series)
Digital weighing by supplier	1 minute continuously	103 litres (1st series) 108 litres (2nd series)	103 l/min (1st series) 108 l/min (2nd series)

The supplier of One Seven® assumes that the shots were exactly 5 seconds.

B 2.3.3 Study by Kiwa into inaccuracy of meters 2014

Pursuant to the above tests, Kiwa Nederland B.V. in Rijswijk, being an independent authority in the field of water measurements, was asked to make a statement about the correctness of IFV's digital and analogue meters and the test setup used.
The water meters used by the supplier were not considered as part of this study.

Test setup
Kiwa was asked to determine the inaccuracy[47] of the two water meters. The inaccuracy of water meters is determined at different volume flows. These volume flows have been determined such that they give a realistic picture of the inaccuracy of water meters when used with different flow rates. The inaccuracy was determined in calibrated calibration installations in Kiwa's test laboratory.

Test results
According to Kiwa[48], the accuracy of the measurement depends on the flow rate used.

---

46 Since no IFV researchers were involved in designing and carrying out this measurement, the supplier of One Seven® is responsible for the accuracy of the data. The supplier stated that it used the same setup and methods for its measurements and that the measurement was recorded on film.

47 By 'inaccuracy' we mean the difference between the value measured by the meter and the actual amount of water that has passed through it.

48 Kiwa, report no. 1407008898, *Determining the inaccuracy of water meters*.

The results are as follows:

Results of inaccuracy of IFV's analogue water meter

Flow rate used (l/h)	Inaccuracy (%)
70	- 1.5%
270	+ 1.4%
1,040	+ 0.8%
1,750	+ 0.5%
3,500	+ 0.1%
7,000	+ 0.1%

Results of inaccuracy of IFV's digital water meter

Flow rate used (l/h)	Inaccuracy (%)
2,000	+ 21.3%
5,000	+ 10.7%
10,000	+ 5.3%
21,000	+ 2.0%
42,000	+ 1.0%
63,000	+ 0.1%
84,000	+ 0.2%
105,000	+ 0.7%
126,000	+ 0.7%

This shows that the digital water meter was created for much higher flow rates than the analogue water meter.

In order to be able to determine the inaccuracy, it was necessary to have some understanding of the flow rates used in the digital and analogue water meters of IFV.

These flow rates had not been determined during the experiments with CAF 2.0 (digital water meter) and the previous experiments with CAF 1.0, LP and HP (analogue water meter).

As the flow rate of the digital water meter in the tests referred to above had not been determined, a supplementary flow rate measurement was conducted for the digital meter[49].

B 2.3.4 Test 3: Flow rate measurement of digital meter and comparison test of analogue water meter relative to the weighing on 21 November 2014

Test setup

[49] The flow rate of the digital meter was measured because the supplier and the manufacturer asked questions about the results of the measurements using that meter. The flow rate of the analogue water meter can be calculated roughly. When conducting the experiments with that meter, 3x3 shots of 1-1.5 seconds from outside the container were applied and 3x3 shots of 1-1.5 seconds halfway into the container, i.e. (again with an error margin in the time measurement) for a time of approx. 18 to 27 seconds. Here, an average of 29 litres of water was measured during the tests with CAF 1.0. Therefore, the flow rate during the tests was between 5,800 l/hour (29 litres / 18 seconds x 3,600 seconds) and 3,867 l/hour (29 litres / 27 seconds x 3,600 seconds). Also taking into account an error margin in the time measurement, the upper limit of the inaccuracy with these flow rates is 0.1% according to Kiwa.

To achieve a good comparison between the flow rate measurement and the experiments conducted with CAF 2.0, it was decided to conduct the flow rate measurement in the same location and using the same test setup and the same fire appliance as the actual experiments with CAF 2.0, including connection to the same underground fire hydrant.

To measure the flow rate of the digital meter, the time it took to fill the tank was measured. This measurement was repeated ten times. In this way it was determined whether the flow rate at which the tank was filled was sufficient to enable the water meter to work properly.

An average water usage of 74 litres was measured during the experiments with CAF 2.0. The hydrant was fully open during the flow rate measurement and the hoses were filled, after which the shutoff valve of the fire appliance was fully opened until 74 litres had passed through it. At that moment, the shutoff valve was closed in one movement and the time recording was stopped. Here, the circumstances were identical to the manner of filling during the previous experiments.

In addition to the flow rate tests, comparison measurements between the analogue water meter and the weighing platforms were also conducted, at the request of the supplier of One Seven®. Contrary to the tests on 12 May, this was carried out at the same location and with the same appliance configuration as the actual tests with CAF 2.0[50]. Again however, this was not in the container, nor with the use of breathing apparatus, walkie-talkies and a time observer present at some distance, as had been the case during the experiments. Just like on 12 May, the time observer, with a stop watch, was in direct contact with, and positioned next to, the jet nozzle operator. For these tests, the fire appliance was placed on weighing platforms and the tank was filled. Five tests with four shots of approx. five seconds each, in the same manner as with the experiments with CAF 2.0, were then conducted. After this, the decrease in weight was measured and then the tank was filled again, measuring how much water had to be added. Both the digital and the analogue meter were used for these measurements.

Test result
The average tank filling time during the flow rate measurement of IFV's digital water meter was 16.2 seconds. This means that the flow rate was (74 l/16.2 sec x 3,600 =) 16,400 l/hour.

The maximum expected deviation for the absolute water measurement with the digital water meter was 5.3%, since it was found that the flow rate was higher than the 10,000 litres per hour indicated in the Kiwa table (but lower than the 21,000 l/hour with an inaccuracy of 2%, also stated in that table). As a result, the inaccuracy of the digital water meter could be expected to at least be less than 5.3%.

This means that 5.3% is the upper limit of the inaccuracy, which clears the water meters from all suspicion. As regards the digital water meter, Kiwa has concluded that the meter works well with a volume flow of greater than 10,060 l/h (10.060 m³/h). Kiwa states that this means: '*that a reliable measurement can be delivered when drawing 74 l in 16.2 s (16.44 m³/h)*[51]'. [52]

---

50 Note! The digital water meter was used for the CAF 2.0 tests, whereas the analogue water meter was used for the CAF 1.0, LP and HP tests that had been carried out previously.
51 That is 16,440 litres per hour.
52 Kiwa came to the conclusion that the analogue water meter gives a reliable measurement at a volume flow greater than or equal to 70 l/h (0.07 m³/h) and less than or equal to 7,000 l/h (7.0 m³/h). Kiwa indicates that this means '*that a reliable measurement can be delivered when drawing 26 l in ≈20s (4.680 m³/h)* [i.e. 4,680 litres per hour]'.

The comparison tests revealed that the analogue meter indicated a comparable value (51.8 litres) relative to the weighing platforms (52 kg). The previous difference between the weighing platforms and the analogue water meter, as found on 12 May, may be explained by the difference in water pressure between the water mains that was then used and the underground fire hydrant used with these tests and with the actual experiments.

After the tests, the supplier and the manufacturer of One Seven® felt the need to conduct another comparison test for the digital water meter relative to the weighing platforms with the same setup as during the tests.

B 2.3.5 Test 4: Comparison test using a digital water meter on 1 December 2014

Test setup

The last water tests were conducted on 1 December 2014, this time to compare the weighing platforms to the IFV digital water meter and, again, to the analogue water meter. These tests were conducted with the same setup and under the same circumstances as on 21 November 2014. Here, ten tests of four shots of approx. four seconds each were conducted while using the digital water meter and four tests while using the analogue water meter. In addition, four rounds where the jet nozzle was open for one minute were carried out, two of which with the digital water meter and two with the analogue water meter.

Results

The comparison tests show the following:

Duration of use	IFV meter used	Average result water meter (l/min)	Average weight measured on the weighing platforms
20 seconds (4x5 sec)	Analogue meter - IFV	53.1 litres	60.0 kg
20 seconds (4x5 sec)	Digital meter - IFV	53.1 litres	52.0 kg
1 minute continuously	Analogue meter - IFV	94.6 litres	100.0 kg
1 minute continuously	Digital meter - IFV	94.0 litres	97.5 kg

The table shows that the meter and the weighing platforms are at variance; in this case, the weighing platforms stated a higher value than the water meters. Given the inaccuracies of both the water meters (see above) and the weighing platforms (not determined) and the large-scale readout of the meter of the weighing platforms (5 kg increments), these differences are within the error margin that was to be expected.

In these comparison tests, the water usage converted into litres per minute when using shots was well above the assumed limit of 135 l/min[53]. This was also the case in the first tests on 12 May 2014. While weighing using the measuring platform, this was 180 l/min (1st measurement) or 156 l/min (second measurement), and it was 159 l/min with the analogue and digital water meters (assuming an exact attack time of 20 seconds). The results of these 1-minute measurements also serve to confirm the significant error margin described above produced by the study method (of shots of a couple of seconds) used.

53 Excluding a possible margin.

B 2.4 Analysis/conclusion

The comparison tests and the study by Kiwa justify the conclusion that:

> it was demonstrated that the measurement of the absolute amount of water was reasonably accurate: the maximum inaccuracy of the digital water meter was 5.3% (and – based on a calculation - the maximum inaccuracy of the analogue water meter was 0,1%)

> in addition, it was demonstrated that, when measuring/spraying for one minute (given that the length of time was the most accurate measurement that was conducted), the resulting flow rate stays below the maximum flow rate stated by the manufacturer[54].

> the measuring method and/or the nature of the measuring method, consisting of pulses of four times five seconds, introduces such an error in respect of the time measurement that, as a result, the flow rate determination/conversion is very inaccurate.

Considering the error margin in the time measurement that was produced by the study method used, as well as the maximum inaccuracy of the meter, the results of the measurements and the expected results (given the error margin) do not conflict with each other. Therefore, it can be assumed that the measurements and their results are reliable.

Comparing the average values measured during the comparison test by the four meters used for the comparison test, it was also found that the average measured values approximated each other.

Measured amounts of water at 4 shots of approx. 5 seconds

Date of test	Analogue meter - IFV	Digital meter - IFV	Digital meter - One Seven	Weighing platform - One Seven
01 May 2014	70.3 litres	64.7 litres	55 litres	58 litres
16 May 2014	-	-	55 litres (1st series) 54.8 litres (2nd series)	60.8 litres (1st series) 56.3 litres (2nd series)
21 November 2014	51.8 litres	-	-	52 litres
01 December 2014	53.1 litres	53.1 litres	-	60 litres (cf. analogue) 52 litres (cf. digital)
Average	58.4 litres	58.9 litres	54.9 litres	56.5 litres
Difference from average total 57.175 (= 100%)	+ 2.1%	+ 3.0%	- 4.0%	- 1.2%

54 Or vice versa: the water usage in all measurements with shots was well above the limit of 135 l/min as stated. The supplier and the manufacturer of One Seven® explain this observation when applying pulses from the fact that pressure builds up in the system (from air, water and foam-forming agent) before the jet nozzle is opened. As explained above, there is a good explanation for this, given the error margin in the time measurement with shots/pulses.

Measured amounts of water with 1-minute measurements

Date of test	Analogue meter - IFV	Digital meter - IFV	Digital meter - One Seven	Weighing platform - One Seven
01 May 2014	122.5 litres	112 litres	102 litres	104 litres
16 May 2014	-	-	106 litres (1st series) 109 litres (2nd series)	103 litres (1st series) 108 litres (2nd series)
21 November 2014	-	-	-	-
01 December 2014	94.6 litres	94.0 litres	-	100.0 litres (cf. analogue) 97.5 litres (cf. digital)
Average	108.6 litres	103 litres	105.7 litres	102.5 litres
Difference from average total 104.95 (= 100%)	+ 3.5%	- 1.9%	+ 0.7%	- 2.3%

Also given these average values (and their deviations which can be explained given the inaccuracies of the different meters), it can be assumed that the measurements using the digital meter with the CAF 2.0 experiments are reliable.

This is all the more true now that the flow rates determined in the experiment and the flow rate used by the supplier and the manufacturer of One Seven® do not conflict with each other. They are within the error margins that can occur given the deviations in the time measurement and within the maximum inaccuracy of the water meter used by IFV for the CAF 2.0 experiments.

Pursuant to the above, the water measurements conducted during the experiments are considered to be reliable and there is no substantiated reason why the water measurements of experiments CAF 1.0 and 2.0 should not be compared to each other.

Annex 3: Kiwa report

This annex contains the Kiwa report about the inaccuracy of the water meters. Contrary to what is stated in section 4.1 of the KIWA report, the setup *did not contain any automatic water supply shut-off,* but a manually operated ball valve was used when filling the water tank. KIWA has confirmed that this does not affect the conclusions in the KIWA report.

140700898-R2 - BRL-K618
3 juni 2015

Beoordeling miswijzing watermeters en testinstallatie

3 juni 2015

Beoordeling miswijzing watermeters en testinstallatie

Kiwa Nederland B.V.
Sir Winston Churchilllaan 273
Postbus 70
2280 AB RIJSWIJK

Tel. 070 414 44 00
Fax 070 414 44 20
info@kiwa.nl
www.kiwa.nl

Colofon

Titel	Bepaling miswijzing watermeters en beoordeling testinstallatie
Projectnummer	140700898-R2 - BRL-K618
Projectmanager	R.R. de Jong
Opdrachtgever	Instituut voor Fysieke Veiligheid
Kwaliteitsborger(s)	K.H. Poortema
Auteur(s)	J.J.C. van der Westen

Dit rapport is niet openbaar en slechts verstrekt aan de opdrachtgever van het project. Eventuele verspreiding daarbuiten vindt alleen plaats door de opdrachtgever zelf.

Inhoud

1 Inleiding

Bij het Instituut voor Fysieke Veiligheid (IFV, of Brandweeracademie) worden metingen uitgevoerd op het waterverbruik van blussystemen. Voor deze metingen gebruikt men 2 watermeters. Bij eerdere metingen is het door IFV gemeten waterverbruik van onderzochte blussystemen door de leveranciers van deze systemen ter discussie gesteld. Om hier duidelijk over te krijgen heeft IFV aan Kiwa Nederland B.V. verzocht onderzoek te doen naar de eventuele miswijzing van de gebruikte watermeters.

In latere instantie heeft het IFV verzocht ook onderzoek te doen naar het vullen van de tank.

Hoofdstuk 2 van dit rapport bevat de meetwaarden die Kiwa Nederland B.V. in haar onderzoek heeft bepaald aangaande de miswijzing van beide watermeters. In hoofdstuk 3 zijn de conclusies aangaande miswijzing opgenomen en wordt nader ingegaan op de toepassingsmogelijkheden van beide watermeters. In hoofdstuk 4 wordt nader ingegaan op de wijze waarop IFV de watermetingen uitvoert.

Hoofdstuk 5 bevat de conclusies.

2 Bepaling miswijzing watermeters

2.1 Volumestromen in watermeters

De miswijzing van watermeters wordt bepaald bij een aantal verschillende volumestromen. Deze volumestromen zijn zo bepaald dat zij een getrouw beeld geven van de miswijzing van een watermeter over het gehele belastinggebied.

2.1.1 Bepaling miswijzing

De miswijzing is bepaald in gekalibreerde ijkinstallaties in het testlaboratorium van Kiwa Nederland B.V. in Rijswijk.

De watermeters zijn ingespannen in een testinstallatie waardoor een hoeveelheid water per tijdseenheid stroomt. De te meten volumestroom kan door middel van een regelventiel worden ingeregeld. De volumestroom wordt ingesteld met behulp van een magnetisch inductieve watermeter.

2.1.2 Maximaal toelaatbare miswijzing Q_n 3,5[1] klasse B (analoge meter)

Onderstaande waarden zijn aangehouden voor de maximaal toelaatbare[2] miswijzing voor in gebruik zijnde watermeters die voor handelsdoeleinden[3] zijn bestemd (zie ook par. 3.2):

Tabel 1: maximaal toelaatbare miswijzing Q_n 3,5

Benaming	Volumestroom	Maximale miswijzing
		In gebruik zijnde
Q_{min}	0,070 m³/h	± 10 %
Q_t	0,280 m³/h	± 4 %
0,3 Q_n	1,050 m³/h	± 4 %
0,5 Q_n	1,750 m³/h	± 4 %
Q_n	3,500 m³/h	± 4 %
Q_{max}	7,000 m³/h	± 4 %

2.1.3 Maximaal toelaatbare miswijzing DN 50 watermeter (digitale meter)

Onderstaande waarden zijn aangehouden voor de maximaal toelaatbare miswijzing voor in gebruik zijnde watermeters die voor handelsdoeleinden zijn bestemd (zie ook par. 3.2):

Tabel 2: maximaal toelaatbare miswijzing DN 50

Benaming	Volumestroom	Maximale miswijzing
		In gebruik zijnde
Q_1 Minimale volumestroom	Niet bekend	± 10 %
Q_4 maximale volumestroom	Niet bekend	± 4 %

2.1.4 Aanvullende eis maximaal toelaatbare miswijzing

IFV heeft bepaald dat een miswijzing kleiner of gelijk aan 10% als acceptabel en voldoende betrouwbaar kan worden geacht bij het testen van blussystemen.

[1] Nominale volumestroom 3,5 m³/h
[2] Maximaal relatief verschil tussen het gemeten en het werkelijke doorstroomde volume bij een bepaalde volumestroom, ten opzichte van het werkelijk doorstroomde volume.
[3] Zoals betaling van de waterrekening

2.2 Miswijzing watermeter Q_n 3,5 m³/h

De eerste watermeter die is beoordeeld is een Itron/Actaris-meter met een nominale volumestroom van 3,5 m³/h, klasse B. De maximale volumestroom bedraagt 7,0 m³/h. De betreffende watermeter is een mechanische watermeter van het “volume”-principe.

Tabel 3: gemeten miswijzing Q_n 3,5

Meternummer	Nr.	Instelling	Aangew.	Opgev.	Tijd	Vol.str.	Miswijzing
		[l/h]	[liters]	[liters]	[sec]	[l/h]	[%]
89402257	1	70	19,8	20,1	1054	69	-1,5
89402257	1	270	101,2	99,8	1295	277	1,4
89402257	1	1.040	503,8	499,7	1725	1043	0,8
89402257	1	1.750	502,4	499,8	1035	1738	0,5
89402257	1	3.500	500,1	499,8	525	3429	0,1
89402257	1	7.000	500,1	499,8	264	6828	0,1

2.3 Miswijzing watermeter DN 50

De tweede watermeter die is beoordeeld is een magnetisch inductieve watermeter met een doorlaat van 50 mm.
Dit type watermeter bevat geen mechanische overbrengingen. De volumestroom wordt bepaald als functie van het spanningsverschil tussen 2 tegenover elkaar geplaatste electroden passeert.
Bij dit type watermeter is het essentieel dat de geleidbaarheid van het gebruikte water voldoet aan de specificaties die door de leverancier zijn opgegeven.

Tabel 4: gemeten miswijzing DN 50

Meternummer	Nr.	Instelling	Aangew.	Opgev.	Tijd	Vol.str.	Miswijzing
		[l/h]	[liters]	[liters]	[sec]	[l/h]	[%]
Flowmaster 2500L	1	1.800	0,0	0,0	600	1.800	XX[1]
Flowmaster 2500L	1	2.000	1246	1027,5	1828	2.024	21,3[2]
Flowmaster 2500L	1	5.000	1107	1000,3	720	5.002	10,7
Flowmaster 2500L	1	10.000	1062	1008,8	361	10.060	5,3[3]
Flowmaster 2500L	1	21.000	7152	7010,8	1200	21.032	2,0
Flowmaster 2500L	1	42.000	7082	7014,4	602	41.947	1,0
Flowmaster 2500L	1	63.000	7032,0	7021,6	400	63.194	0,1
Flowmaster 2500L	1	84.000	7067	7054,0	303	83.810	0,2
Flowmaster 2500L	1	105.000	7116	7064,8	242	105.096	0,7
Flowmaster 2500L	1	126.000	7121	7073,8	202	126.068[4]	0,7

[1] Niet meetbaar
[2] Onderstreepte meetwaarden betreffen meetwaarden met een miswijzing groter dan 10% volgens 2.1.3.
[3] Akkoord volgens 2.1.4.
[4] Maximale pompcapaciteit ijkinstallatie

3 Beoordeling testresultaten

3.1 Toepassingsgebied

Bij de bepaling van miswijzing zijn als criteria de maximale waarden aangehouden die in Nederland worden gebruikt om het water in rekening (handelsdoeleinden) te brengen dat door consumenten wordt afgenomen van drinkwaterbedrijven. Bij het IFV zijn de watermeters niet bedoeld om afgenomen water in rekening te brengen maar om het waterverbruik van verschillende soorten blussystemen met elkaar te meten.

Misschien ten overvloede kan nog worden vermeld dat genoemde meters bedoeld zijn voor met meten van onsamendrukbare vloeistoffen, zoals water.

3.2 Meetbereik van de toegepaste watermeters

IFV gebruikt 2 watermeters om volumestromen te bepalen:

- Een mechanische (analoge) watermeter met een nominale capaciteit van 3,5 m³/h en een maximum van 7 m³/ h. Deze genereert betrouwbare metingen voor het gehele bereik van 0,07 tot en met 7 m³/h.
- Een magnetisch inductieve flowmeter (digitale) met een nominale diameter van 50 mm en een gemeten maximale capaciteit van 126 m³/h.
  - Bij een volumestroom minder dan 5 m³/h zijn de metingen met deze meter onbetrouwbaar.
  - Deze watermeter levert een betrouwbare meting op vanaf 10 m³/h tot en met 140 m³/h.
  - In het gebied tussen de 5 m³/h en 10 m³/h is niet duidelijk of de meter betrouwbare metingen oplevert.

3.3 Vergelijking specifieke volumestromen Q_n 3,5 m³/h (analoge) DN50 (digitale watermeter)

Gezien de volumestromen die met beide meters kan worden gemeten zijn er geen gelijke volumestromen die met beide meters gemeten met zekerheid een betrouwbare meting opleveren.

Bij afname van 26 l in ≈20 s (4,680 m³/h) kan de analoge meter een betrouwbare meting leveren, de digitale niet.

Bij het vullen van een tank met 74 l in 16,2 sec. (16,444 m³/h) ligt de volumestroom tussen 10,060 en 21,032 m³/h. In dit gebied verandert de miswijzing van de digitale meter van 5,3% naar 2,0%. Uit 3.2 blijkt dat bij deze volumestroom betrouwbare metingen kunnen worden uitgevoerd met de digitale meter.

Opmerking:
De omschreven volumestromen en tijden zijn ontleend aan de IFV rapporten:

- *Voor de analoge meters: "Verkoelende experimenten met water en schuim (Arnhem 2013), Dikkenberg, R. van den, Groenewegen, K en Kobus, M."*
- *"Schuim en water opnieuw belicht (2015), Dikkenberg, R. van den, Groenewegen, K en Kobus, M., Wolfs, L"*

4 Testinstallatie

In de inleiding is aangegeven dat de leveranciers de meetwaarden van de IFV-watermeters ter discussie stelden. In hun perceptie zouden de blussystemen minder water moeten gebruiken dan vastgesteld tijdens het testen. Zoals uit voorgaande hoofdstukken blijkt voldoen de watermeters, volgens 2.1, 2.2 en 2.3, zoals mag worden verwacht. De gemeten volumestromen voldoen aan de eisen die worden gesteld aan gebruikte watermeters als deze worden toegepast binnen de productspecificaties aangevuld met het gestelde in 2.1.4.

In dit hoofdstuk schetst Kiwa een beeld van de werking van de testinstallatie en is beoordeeld of deze op zodanige wijze heeft gefunctioneerd dat de uitgevoerde metingen als betrouwbaar mogen worden beschouwd.

Omdat er tijdens de onderzoeksperiode geen metingen zijn uitgevoerd was het voor de onderzoeker van Kiwa niet mogelijk om de metingen te schouwen. Dit hoofdstuk is tot stand gekomen op basis van informatie die is aangeleverd door IFV, aangevuld met antwoorden op een aantal vragen die Kiwa heeft voorgelegd aan IFV.

4.1 Huidige werkwijze[1]

Voor het testen van de blussystemen wordt op locatie een testinstallatie opgebouwd volgens Foto 1.
Er wordt water afgenomen via een opzetstuk op een standpijp die is gemonteerd op een brandkraan in het openbare net. De verbindingen tussen het opzetstuk, watermeter en blusvoertuig worden bewerkstelligd door standaard 3' bluswaterslangen.
Vanuit het opzetstuk stroomt het water via de watermeter naar de voorraadtank van het blusvoertuig. Met de pomp van het drukluchtsysteem in het blusvoertuig wordt het water op druk gebracht en wordt het water via het te testen blussysteem afgevoerd.
Men meet de gebruikte hoeveelheid testwater door de tank in het blusvoertuig steeds tot een bepaalde hoogte bij te vullen en met behulp van de watermeter te bepalen hoeveel water in de tank moet worden toegevoerd om de tank te vullen tot het startniveau. De tank wordt gevuld tot de automatische afslag in de tank de watertoevoer stopt. Een teveel aan water dat wordt afgevoerd via de overstortopening van de tank wordt opgevangen en daarna afgetrokken van de geregistreerde hoeveelheid van de watermeter.

[1] Beschrijving en foto aangeleverd door IFV.

Foto 1: Testopstelling

De tankopstelling en leidingloop in het blusvoertuig is niet zichtbaar.

4.2 Testinstallatie

Zoals uit 4.1 blijkt meet de watermeter dus niet direct het watergebruik van het te testen blussysteem maar de hoeveelheid water minus de opgevangen hoeveelheid via de overstort, die door het blussysteem wordt gebruikt.

4.2.1 De watermeter in de testinstallatie

Het testwater wordt afgenomen vanaf het lokale distributienet. De waterdruk in distributienetten in Nederland ligt tussen 4 en (incidenteel) 10 bar. De watertemperatuur is hoger dan 4°C en lager dan 25°C. Deze waterdruk en temperatuur zijn geen belemmering van het, binnen de specificaties, functioneren van de watermeter.
Bij de levering van watermeters worden installatie-instructies van de leverancier meegeleverd. Voor het functioneren van de watermeter binnen zijn specificaties moeten deze instructies worden aangehouden.

Aangaande het gebruik van de watermeter heeft Kiwa de volgende vragen:

- Werden de watermeters gebruikt in een tegendruk situatie?
- Zijn er vormvaste, of zich als vormvast gedragende, leidingdelen toegepast van minimaal 10D vóór de meter tot en met minimaal 5D na de watermeter?
- Hadden de aansluiteinden van de watermeter en gekoppelde leidingdelen boven- en benedenstrooms dezelfde doorlaat hebben als de doorlaat van de watermeter?

5 Conclusies

5.1 Watermeters

5.1.1 Conclusie algemeen

Beide typen watermeters zijn enkel geschikt om water te meten met een temperatuur hoger dan 4°C en de temperatuur waarbij zich nog geen dampbellen beginnen te vormen en kunnen een betrouwbare meting leveren binnen de gegevens specificaties van de onderzochte watermeters.

5.1.2 Watermeter Qn 3,5 m³/h (analoog)

Deze watermeter voldoet op alle volumestromen, groter of gelijk dan 0,07 m³/h, en kleiner of gelijk aan 7,0 m³/h aan de eisen die aan de maximaal toelaatbare miswijzing worden gesteld in gebruik zijnde watermeters die worden gebruikt voor handelsdoeleinden.
Dit betekent dat bij afname van 26 l in ≈20s (4,680 m³/h) een betrouwbare meting kan worden geleverd.

5.1.3 Watermeter DN 50 (digitaal)

- Bij een volumestroom kleiner of gelijk aan 1,80 m³/h kan geen miswijzing worden bepaald omdat het telwerk geen signalering afgeeft;
- Bij volumestromen van vanaf 2,024 m³/h tot en met 5,002 m³/h voldoet de watermeter niet aan de eisen die aan de maximaal toelaatbare miswijzing zijn gesteld aan in gebruik zijnde watermeters die worden gebruikt voor handelsdoeleinden;
- Bij een volumestroom groter dan 10,060 m³/h voldoet de watermeter aan de eisen die zijn gesteld aan de maximaal toelaatbare miswijzing van in gebruik zijnde watermeters voor gebruik voor handelsdoeleinden, uitgaande van de eis in 2.1.4. Dit betekend dat bij afname van 74 l in 16,2 s (16,44 m³/h) een betrouwbare meting kan worden geleverd.

5.1.4 Vergelijking watermeters

- Bij een volumestroom kleiner of gelijk dan 7,0 m³/h of groter of gelijk dan 10,06 m³/h kan één van beide watermeters een betrouwbare meting leveren;
- Bij een volumestroom groter dan 7,0 m³/h kan de analoge meter niet meten en is het voor de digitale meter bij een volumestroom groter dan 5,002 m³/h en lager dan 10,06 m³/h (voor handelsdoeleinden) niet duidelijk of deze een betrouwbare meting kan leveren.
- Daarmee zijn er geen volumestromen waarop beide watermeters betrouwbaar met elkaar kunnen worden vergeleken.

5.2 Testinstallatie

5.2.1 Conclusie toepassing watermeter in de testinstallatie

- Op Foto 1 is te zien dat de gebruikte slangen zich als vormvaste leidingdelen gedragen vanaf minimaal 10D vóór de meter tot en met minimaal 5D na de watermeter.
- In volledig gevulde toestand kunnen de gebruikte slangen zich vormvast gedragen. Men kan visueel vaststellen dat slangen zich vormvast gedragen tijdens de test. Hieruit kan men afleiden dat er geen situatie ontstaat waarin benedenstrooms van de watermeter een druk lager dan de atmosferische kan ontstaan en er dus sprake van een tegendruksituatie zou zijn.