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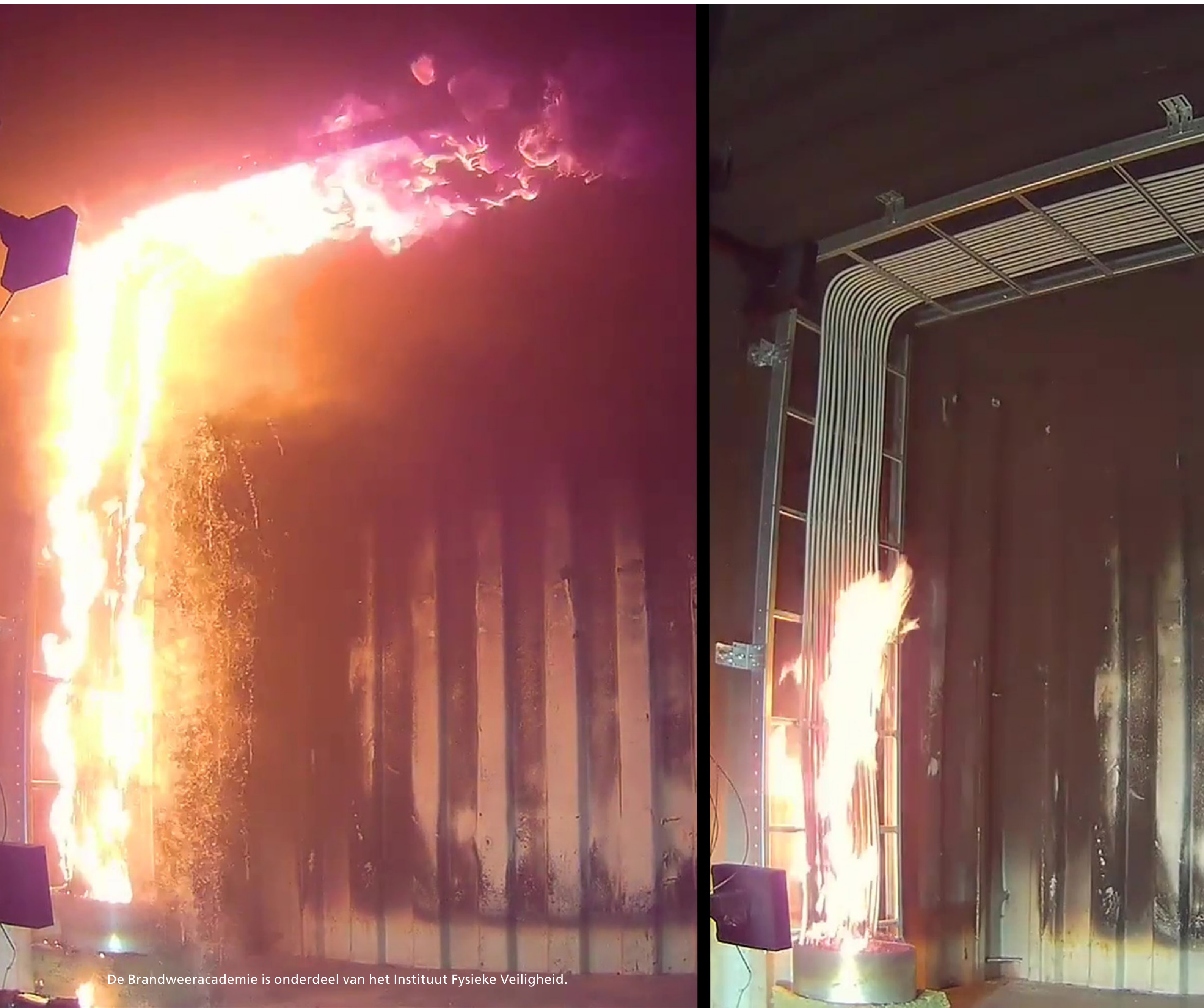
Impression tests cables



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Content

Introduction

Background

Electricity has become a vital part of everyday life over the past 100 years. However, in addition to the benefits it brings, electricity can also be dangerous if not managed properly. Every year, about 30 people in the Netherlands and about 5000 people in the EU die because of a residential fire. Statistics show that at least 26 % of residential fires in the Netherlands are caused by an electrical problem in (household) equipment or installations (Annual overview of fatal residential fires 2020, 2021). International research shows comparable figures.

According to the Forum for European Electrical Domestic Safety (FEEDS), electrical safety issues are mainly the result from an unsuitable design of the electrical installation, an inappropriate use of the installation or a lack of proper maintenance (Residential electrical safety - How to ensure progress, 2017). However, there is another problem: according to Europacable and FEEDS, poor and sub-standard electrics and fraudulent products are finding their way into the market, increasing the risk of electrical safety issues. Both parties voiced their concerns during a meeting of the European Fire Safety Alliance (EuroFSA Network Meeting, 2017).

The European Fire Safety Alliance (EuroFSA) is a project set up by an alliance of professionals from within the European fire sector, including Europacable and the Fire Service Academy. The aim of the project is to reduce the risk from fire in the home. In 2020 the EuroFSA published the Safety Action Plan, with six focus areas and ten action points meant to improve European fire safety (European Fire Safety Action Plan, 2020). The plan clearly states that products' and systems' compliance with national and EU standards and regulations is essential for making Europe safer.

Regarding cables, all cables used in the European Union and permanently installed in any type of building are subject to the Construction Products Regulation (CPR). It is important that cables are compliant with the CPR, to make sure that cables reflecting the appropriate CPR classification are used in buildings to assure the required level of fire safety. Using classes of cables not in line with required levels of fire safety increases the risk of electrical safety issues which can result in a fire or a fire propagating faster than with classes of cables supporting appropriate fire safety performances.

Europacable supports the Safety Action Plan and recommends the use of CPR compliant high performance cables in buildings. To study the difference in fire behaviour, Europacable has asked the Fire Service Academy – as partner in the EuroFSA – to perform impression tests with high performance cables and basic performance cables in a realistic environment (high or basic is the performance regarding the ignition and burning behaviour of the cables).

Purpose and research questions

The purpose of this research is to get an impression of the fire behaviour of the high performance and basic performance cables and the probability of escape and survivability for people present in the built area when these different kinds of cables are ignited. In addition, this research should provide a comparison between the high performance cables and the basic performance cables. To achieve these two goals, it is necessary to test the fire behaviour in a realistic environment. Therefore, this study does not involve laboratory tests, but impression tests in an environment that resembles a building. In addition, the fire development in an office with the fire starting in the basic cables is investigated. Based on these objectives the following research questions have been asked:

Research question 1:
What is the fire behaviour in a single room environment of high performance cables and basic performance cables when exposed to an ignition source of burning methanol?

Research question 2:
What is the probability of escape and survivability in a single room environment when only the cables are burning?

Research question 3:
How does a fire propagate and develop in an office environment with a fire starting in the basic performance cables?

Research question 4:
What is the probability of escape and survivability in an office environment with a fire starting in the basic performance cables?

Scope

As mentioned above, the purpose is to get an impression of the fire behaviour, the probability of escape and survivability in a single room environment and an office environment. To get a good impression, a limited number of fire tests (experiments) have been carried out. However, it should be noted that there is no such thing as a standardized single room environment, standardized office environment or representative fire scenario. That is the reason why the tests are carried out in a room that resembles a single room environment or an office environment and a fire scenario that is relatively common. This means that this study is descriptive and is not intended to provide a comprehensive theory of the fire behaviour, probability of escape and survivability in the built environment.

Reading guide

In the first chapter, the research method will be explained. The second chapter presents the results of the tests (1 and 2) with both types of cables and a comparison between the two, while in the third chapter the results of the test in the office environment (3) are presented. In the fourth chapter the research questions are answered. The fifth and last chapter contains a discussion of the results and findings.

1 Research method

This chapter explains how the experiments were carried out (section 1.1) and how the data were analysed (section 1.2).

1.1 Experimental design

This section describes the experimental design by providing a description of the test facility and fire room, the objects, the ignition source, measurements and measurement protocol and test protocol.

1.1.1 General description

The experiments took place on April 9, 2021. They were carried out on Troned Twente Safety Campus, the Netherlands, a fire training area. In this area a 20 feet ISO container is situated, which was used as the fire room during the tests. The measurements of the ISO container are listed in table 1.1.

Table 1.1 The dimensions of the ISO container

	Length	Width	Height
Inside	5,90 m	2,35 m	2,39 m
Outside	6,06 m	2,44 m	2,59 m

The floorplan and an exterior view of the ISO container can be found in figure 1.1 and figure 1.2.

Figure 1.1 Floor plan

Figure 1.2 Exterior view of the container

1.1.2 Objects

To get an impression of the fire behaviour, two different kinds of cables were tested. The characteristics of the cables are presented in table 1.2.

Table 1.2 Characteristics of the cables

	Specifications	Euroclass fire safety classification (Understanding CPR Cable Classes en certification)			
		General classification	Smoke opacity	Flaming droplets	Acidity
High performance cables	3x2,5 mm2 Ymz1K (XLPE insulated, LSOH filler/sheathed) 1 kV cable	B2ca *(Products that are combustible but show very little burning)*	s1 *(s1a with visibility over 80% / s1b with visibility over 60% and below 80%)*	d1 *(Fall of droplets and inflamed particles that persist for less than 10 seconds)*	a1 *(Very low acidity)*
Basic performance cables	3x2,5 mm2 XmvK (XLPE insulated, PVC filler/sheathed) 450/750V cable	Eca *(Products where a small flame attack is not causing large flame spread)*	-[1]	-	-

1.1.3 Ignition source

The ignition source consisted of 2,5 litres of methanol in a round metal tray with a diameter of 35 centimetres. The top of the metal tray was positioned underneath the cables at the same height as the bottom of the cables (see figure 1.3). The methanol was ignited with a gas burner.

[1] Please note that the European fire classification system for cables does not give the possibility for Euroclass Eca to define the subclasses for smoke, droplets and acidity.

Figure 1.3 Position of the metal tray with methanol

1.1.4 Measurements and measurement protocol

During the experiments temperature, radiation heat flux, carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2) and nitrogen oxides (NOx) were measured. The measurements started when the object was exposed to the ignition source.

The temperature was measured at two positions in the fire room, on five levels (0.5, 0.9, 1.5, 1.8 and 2.2 meters). The gas measurements (CO, CO_2, NOx, and O_2) were taken at two positions and on two levels (0.5 and 1.5 meters). Radiation heat flux was measured at two positions on two levels (0.5 and 1.5 meters). On each level one meter was directed to the fire source and another meter faced upwards to the hot smoke layer.

There were also two heat-resistant video cameras placed in the fire room. One camera was placed on the floor and another one at approximately 0.7 meters above the floor. Both were directed to the fire source. In addition, two action cameras were used to record the fire behaviour and the release of smoke. One camera was placed on the floor in the doorway and another camera was placed outside. Both cameras faced the fire source.

The details of the measurements, tools and position are listed in table 1.3 and figure 1.4.

Table 1.3 Details of the measurements

Parameter	Measurement tool	Frequency	Position	Details
Temperature	Thermocouple tree	5x per second	2 positions	5 levels: 0.5, 0.9, 1.5, 1.8 and 2.2m
Radiation heat flux	Heat flux meter	5x per second	1 position	2 levels: 0.5 and 1.5m On each level 1 meter faces fire source and 1 meter faces hot smoke layer

Carbon monoxide (CO)	Testo's	Every 2 seconds	2 positions	2 levels: 0.5 and 1.5m
Carbon dioxide (CO_2)	Testo's	Every 2 seconds	2 positions	2 levels: 0.5 and 1.5m
Oxygen (O_2)	Testo's	Every 2 seconds	2 positions	2 levels: 0.5 and 1.5m
Nitrogen oxides (NO_x)	Testo's	Every 2 seconds	2 positions	2 levels: 0.5 and 1.5m

The measurement tools for the gases were placed through holes in the wall of the container, as shown in figure 1.4. In this way the measurement tools could be protected against heat and safely be retrieved if necessary. However, this meant that the measurements took place approximately 30 cm from the wall of the fire room, while it would be more obvious to take measurements in the middle of the room. This choice was made in favour of the safety of the measurement tools.

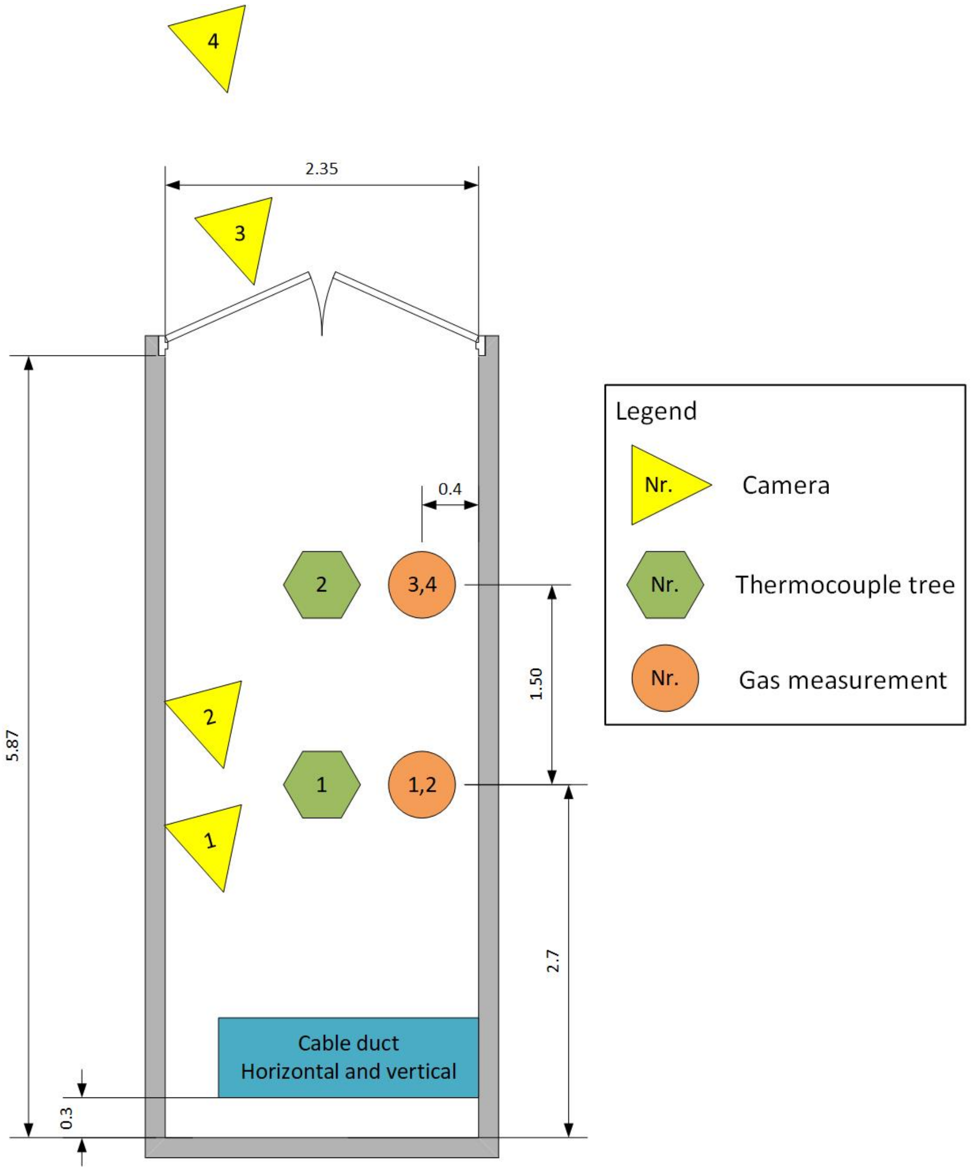

Figure 1.4 Measurement tools and location on the floor plan

The experiments were carried out in an empty container with only the measurement tools inside, as shown in figure 1.5.

Figure 1.5 Experimental set-up inside the container for the experiments with the high performance and the basic performance cables

For the experiment with the basic performance cables in an office environment, the container was equipped with office equipment. This consisted of a desk, desk chair, computer monitor, mouse and keyboard, armchair, cupboard and artwork on the wall. The walls of the container were lined with plasterboard and there was carpet on the floor. The set-up is shown in figure 1.6.

Figure 1.6 Experimental set-up inside the container for the experiment with the basic performance cables in an office environment

1.1.5 Test protocol

The fire tests were carried out in the fire room. One door of the fire room was left completely open during the test.

The following protocol was used:

> Object was ignited with methanol as an ignition source. If no flames were visible after burning the methanol, the test was aborted.

> If flames were visible after burning the methanol, the test was terminated when the object was (largely) burned.

> If a flashover occurred the fire was suppressed with water within a few minutes to prevent damage to the fire room and measuring equipment.

In table 1.4 a summary of the fire tests is presented.

Table 1.4 Fire tests

Object	Door position	Ignition source	Test no.
High performance cables	Door open	Methanol	1
Basic performance cables	Door open	Methanol	2
Basic performance cables in an office environment	Door open	Methanol	3

1.2 Data analysis

After the experiments, the measured data were analysed and compared with the threshold values for escape and survivability. In this paragraph a short summary of the method used to analyse the data and determine the possibility to escape and survive is given. A more detailed explanation can be found in the report smoke propagation in residential buildings (Fire Service Academy, 2020, section. 2.5.2).

As it is important during a fire that the available safe escape time (ASET) is longer than the required safe escape time (RSET), the possibility of escape and survivability for people who are present until the moment they escape or are rescued are important factors in preventing fire casualties. The conditions to which people are exposed and their vulnerability to those conditions are decisive for the available safe escape and survival time.

The conditions that influence occupants' possibility of escape and survivability in the event of fire are:

> irritant and asphyxiant gases

> heat

> visibility.

These fire conditions can lead to the possibility of escape being impaired, a life-threatening situation, or even a fatal situation (see figure 1.7).

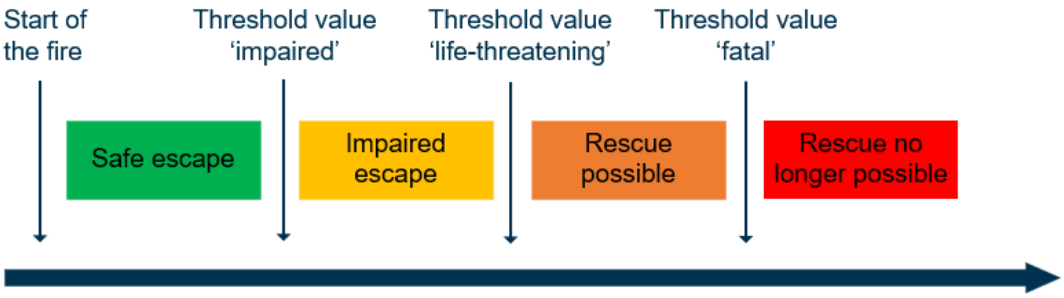

Figure 1.7 Diagram of the possibility of escape and survivability in the event of a fire

The threshold values are based on the *SFPE Handbook* (Purser & McAllister, 2016). These values have also been used in the Fire Service Academy's research into smoke propagation in residential buildings *(Smoke propagation in residential buildings. The main report on the field experiments conducted in a residential building with internal corridors*, 2020).

According to the *SFPE Handbook*, the following methods are important for determining when people's possibility of escape and survivability are threatened:

> The Fractional Effective Concentration (FEC) or Fractional Irritant Concentration (FIC). This is the ratio between the exposure concentration at any time during a fire and the exposure concentration predicted to significantly compromise the possibility of escape and survivability.

> The Fractional Effective Dose (FED) or Fractional Lethal Dose (FLD). This is the ratio between the exposure dose – the concentration and the duration of exposure – and the exposure dose predicted to significantly compromise the possibility of escape and survivability.

In order to determine the FED/FLD or FEC/FIC value at which exposed people can no longer escape safely or survive, a sensitivity factor (sf) has been established (ISO 13571, 2012). This sensitivity factor depends on the vulnerability of the people in question and the fire conditions to which they have been exposed. By definition, in the ISO standard and the *SFPE Handbook*, the value sf = 1 represents the median of the distribution (average population), meaning that 50% of the population are less susceptible and 50% are more susceptible. In addition, sensitivity factors are mentioned that take into account people's vulnerability, namely a value of sf = 0.3 for the vulnerable population (11.4%) and a value of sf = 0.1 for the highly vulnerable population (1.1%).

An overview of the threshold values of the *SFPE Handbook* can be found in table 1.5 on the next page.

Table 1.5 Overview of the threshold values according to the SFPE Handbook

Fire condition	Method	Impaired escape			Life-threatening			Fatal		
		Highly vulnerable	Vulnerable	General	Highly vulnerable	Vulnerable	General	Highly vulnerable	Vulnerable	General
Irritant gases	FIC/FLD	0.1	0.3	1.0	0.5	1.5	5	0.1	0.3	1.0
Asphyxiant gases	FED_{IN}	-	-	-	0.1	0.3	1.0	0.2	0.6	2.0
Heat	FED_{heat}	0.1	0.3	1.0	0.8	2.4	8.0	1.2	3.6	12.0
Visibility[2]	FEC_{smoke}	0.1	0.3	1.0	-	-	-	-	-	-

[2] In the experiments of this study the visibility was not measured.

2 Cable tests

In this chapter the results of the cable tests are presented in the following sections:

- Results of the tests (section 2.1 for the high performance cables and section 2.2 for the basic performance cables)
- Comparison of the high performance and basic performance cables (section 2.3).

The results are presented as follows:

- Results of the tests
  - Photos of the test
  - Temperature graph
  - Oxygen concentration graph
  - Carbon monoxide concentration graph
  - Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) for each group at a height of 0,5 and 1,5 m
- Comparison of the high performance and basic performance cables
  - Photos of the test.

In the tables with the times for the different situations, the following symbols, icons and colours are used (see figure 2.1).

	Safe escape
	Impaired escape
	Life-threatening situation
	Fatal situation

	Highly vulnerable
	Vulnerable
	General

Figure 2.1 Symbols for four situations (left) and icons of three groups (right)

The results and the analysis in this chapter are a summary of all results and a more extensive analysis. The following appendixes provide the basis for the results and analysis of this chapter:

- Appendix 1: graphs of all the measured values during the tests
- Appendix 2: graphs with the values regarding the possibility of escape and survivability for the different methods (FIC, FLD, FEDin, FEDheat) for each measurement location and test.
- Appendix 3: images of the tests.

2.1 High performance cables (test 1)

Below the results of the test are presented with:

- Photos of the test (see figure 2.2 to figure 2.7)
- Graphs of measured values during the test (see figure 2.8 to figure 2.10)

> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.1).

Figure 2.2 Start test

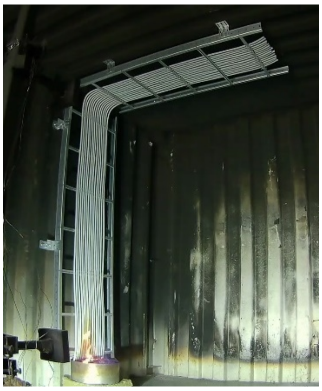

Figure 2.3 Four minutes after start test

Figure 2.4 Seven minutes after start test

Figure 2.5 Ten minutes after start test

Figure 2.6 Twenty minutes after start test

Figure 2.7 Cables after the test

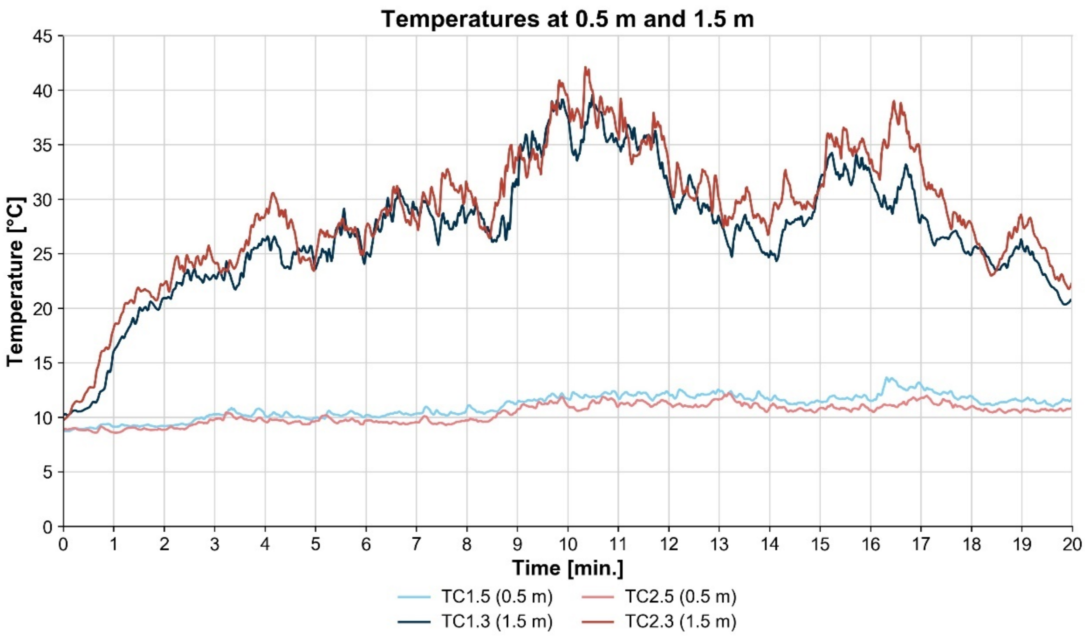

Figure 2.8 Temperatures at 0.5 and 1.5 m height [°C] for test 1

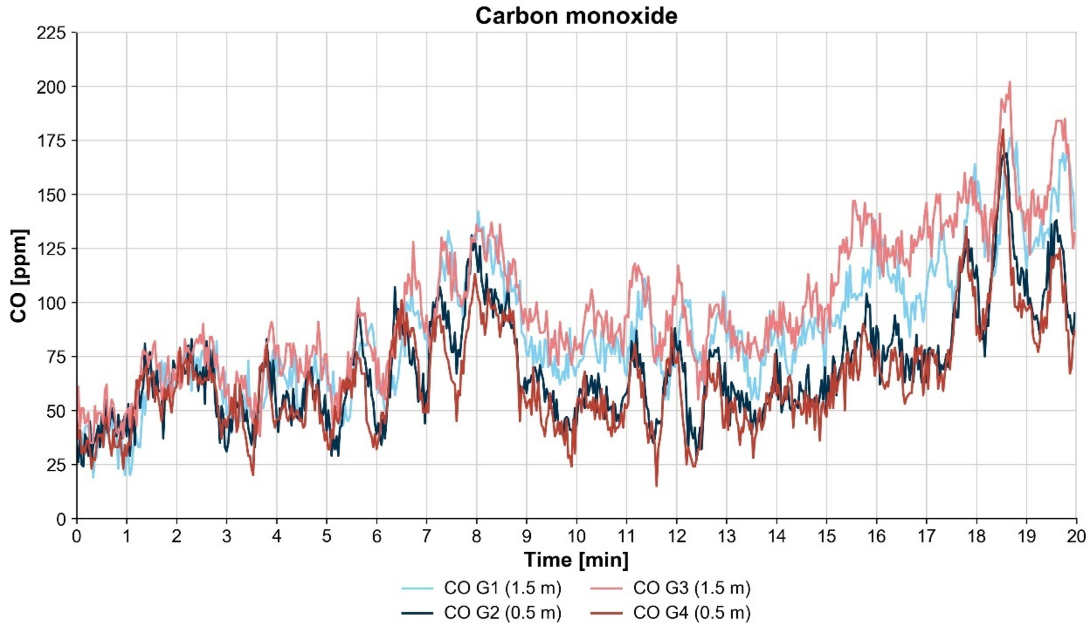

Figure 2.9 Carbon monoxide concentration at 4 locations [ppm] for test 1

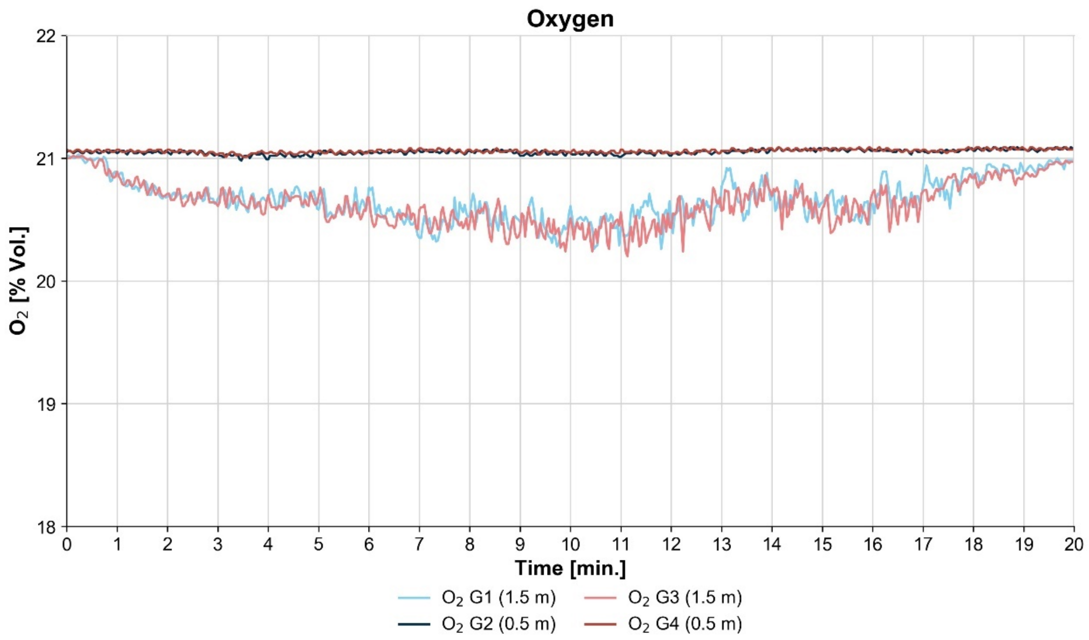

Figure 2.10 Oxygen concentration at 4 locations [% vol.] for test 1

Table 2.1 Times for the possibility of escape and survivability (in minutes) for test 1

Height												
0.5 m	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.
1.5 m	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.

Note: N.R. means limit values were not reached during the test. For the green smiley > 20 means that a safe escape is possible for the complete duration of the test.

Analysis
The fire reached its peak intensity after 10 minutes. After 16 minutes the fire died down slowly. After 20 minutes only smalls flames were visible. A few minutes later the fire died out almost completely. The cables needed an external source of heat (energy) to keep burning.

During the test, the maximum temperature was about 110 °C. at the start of the test a carbon monoxide concentration of about 25 parts per million (ppm) was measured. This was probably caused by a little amount of carbon monoxide in the fire room from a previous test.. The peak carbon monoxide concentration was about 200 ppm. As the door of the fire room was open, plenty of fresh air entered the fire room and smoke ventilated to the outside. The highest temperatures were measured at the heights of 1,8 and 2,2 meter. At the lower heights there were probably not many hot smoke gases that were flowing to the outside of the container. The peak carbon monoxide concentration would probably have risen at greater height or with a closed door. Within this test the limit values for escape and survivability were not reached. A fire in just this set of high performance cables with the door of the fire room open will not result in an impaired escape or a life-threatening situation.

2.2 Basic performance cables (test 2)

Below the results for the test are presented with:
> Photos of the test (see figure 2.11 to figure 2.16)
> Graphs of measured values during the test (see figure 2.17 to figure 2.19)
> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.2).

Figure 2.11 Start test

Figure 2.12 Two minutes after start test

Figure 2.13 Four minutes after start test

Figure 2.14 4:45 minutes after start test (burning droplets)

Figure 2.15 Ten minutes after start test

Figure 2.16 Cables after the test

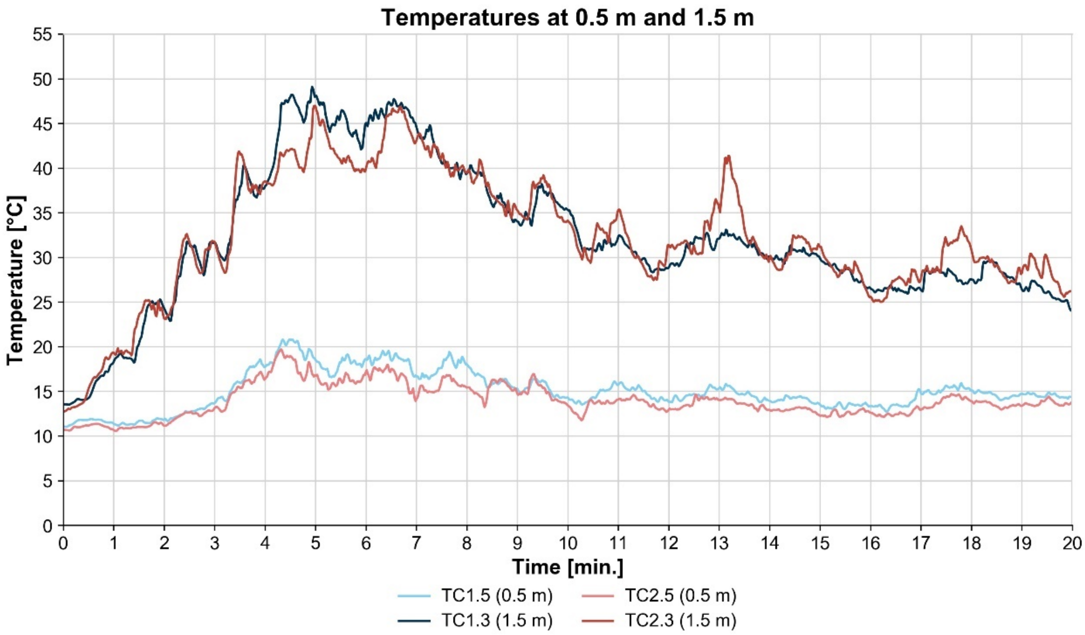

Figure 2.17 Temperatures at 0.5 and 1.5 m height [°C] for test 2

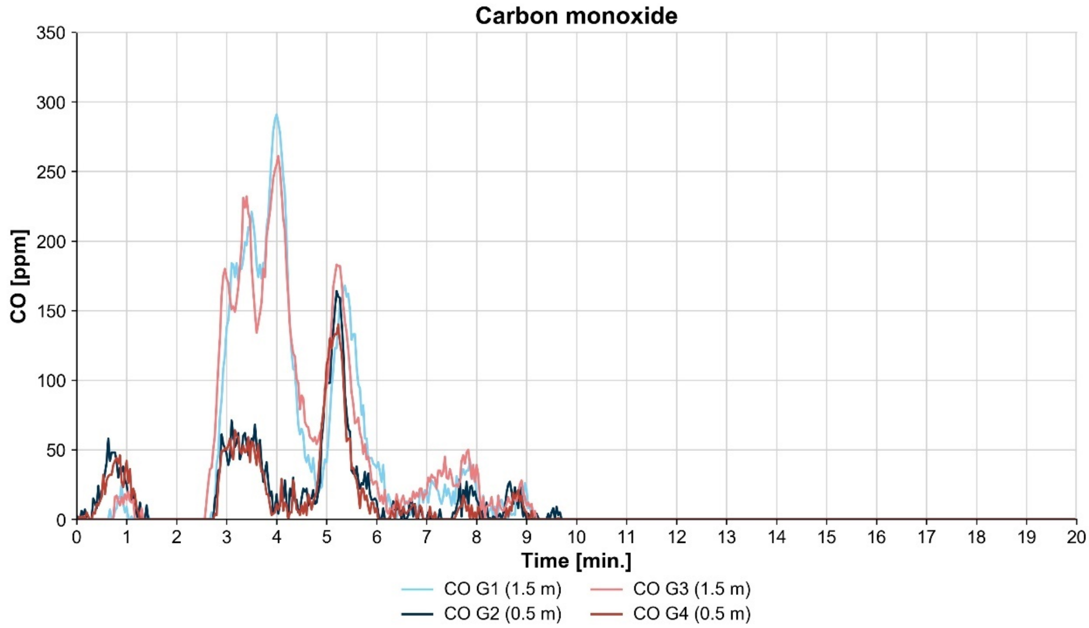

Figure 2.18 Carbon monoxide concentration at 4 locations [ppm] for test 2

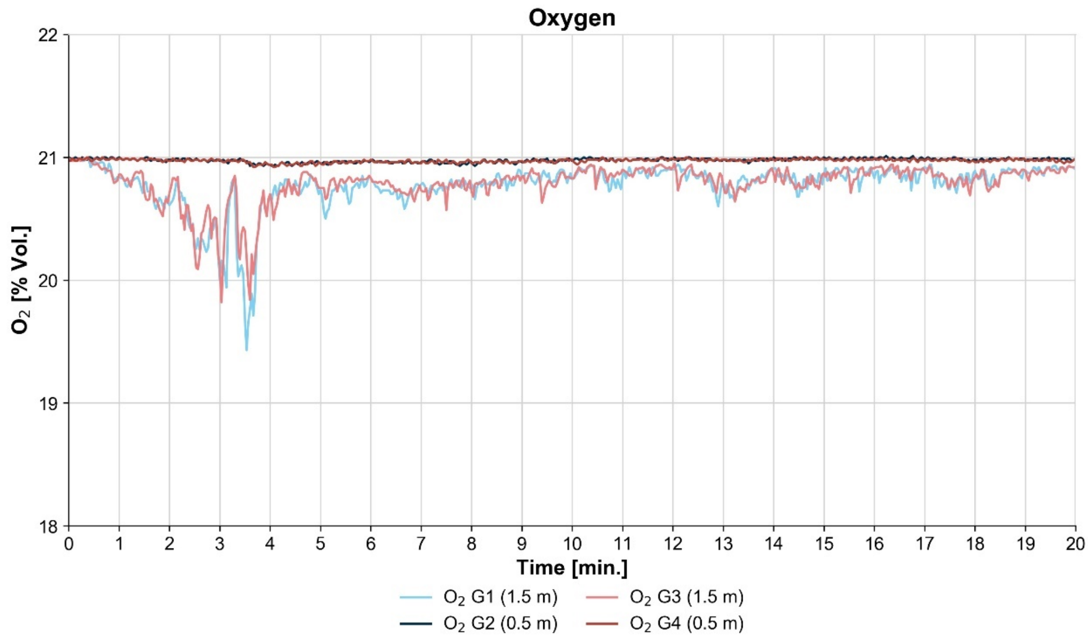

Figure 2.19 Oxygen concentration at 4 locations [% vol.] for test 2

Table 2.2 Times for the possibility of escape and survivability (in minutes) for test 2

Height												
0.5 m	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.
1.5 m	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.	>20	N.R.	N.R.	N.R.

Note: N.R. means limit values were not reached during the test. For the green smiley > 20 means that a safe escape is possible for the complete duration of the test.

Analysis
After 1,5 minutes of fairly slow fire propagation, the fire started to propagate much quicker. Within 1 minute it reached the horizontal part of the cables and after 4 minutes and 30 seconds burning droplets started to fall from the horizontal part of the cables. 5 minutes after the fire started, the vertical part of the cables was almost completely on fire. After 8 minutes and 30 seconds the cables were nearly totally burned away, and the fire nearly died out.

During the test, the maximum temperature was around 340 °C. The peak carbon monoxide concentration was almost 300 ppm. As the door of the fire room was open, plenty of fresh air entered the fire room and smoke ventilated outside. The highest temperature was measured at 1,8 and 2,2 meter. At the lower heights there were probably not many hot smoke gases that were flowing to the outside of the container. The peak carbon monoxide concentration would probably have risen at a greater height or with a closed door. Within this test the limit values for escape and survivability were not reached. A fire in just this set of basic performance cables with the door of the fire room open will not result in an impaired escape or a life-threatening situation.

2.3 Comparison of the high performance and basic performance cables

In this section the burning behaviour of the high and basic performance cables are compared. Photos of the two tests are presented below in order to illustrate the difference in burning behaviour (see figure 2.20 to figure 2.25).

Figure 2.20 Fire size high performance cables after 3 minutes

Figure 2.21 Fire size basic performance cables after 3 minutes

Figure 2.22 Maximum fire size high performance cables (t = 10 min.)

Figure 2.23 Maximum fire size basic performance cables (t = 4:32 min.)

Figure 2.24 High performance cables after the test

Figure 2.25 Basic performance cables after the test

Analysis
The difference in burning behaviour is impressive. With the high performance cables, a fire propagates slow, reaching its maximum size after 10 minutes. The basic performance cables reach the peak fire size after 4 minutes and 32 seconds and the cables are completely burned away after 10 minutes. With the basic performance cables, a fire propagates fast vertically and keeps on spreading through the rest of the cables. The high performance cables only burn in the section where they are impinged by the flames from the ignition source. Further away from the ignition source, where the cables are exposed to less heat from the ignition source, the fire in the cables dies out.

Another striking difference is the falling of burning droplets from the basic performance cables. When the horizontal part of the cables is involved in the fire, multiple droplets fall on the floor and keep on burning there. This could result in a secondary fire spreading inside a room. No burning droplets were seen in the test with the high performance cables. In this test, the horizontal part of the cables was not involved in the fire. It is unclear whether falling droplets would have been observed had the horizontal part of the high performance cables been involved in the fire.

3 Office environment test (test 3)

In this chapter the results of the test with the basic performance cable in an office environment are presented with:

- Photos of the test (see figure 3.2 to figure 3.7)
- Graphs of measured values during the test (see figure 3.8 to figure 3.10)
- Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 3.1).

In the table with the times for the different situations, the following symbols, icons and colours are used (see figure 3.1).

(green smiley)	Safe escape
(yellow face)	Impaired escape
(orange face)	Life-threatening situation
(red face)	Fatal situation

(icon)	Highly vulnerable
(icon)	Vulnerable
(icon)	General

Figure 3.1 Symbols for four situations (left) and icons of three groups (right)

The result and the analysis in this chapter are a summary of all results and a more extensive analysis. The following appendixes provide the basis for the results and analysis in this chapter:

- Appendix 1: graphs of all the measured values during the tests
- Appendix 2: graphs with the values regarding the possibility of escape and survivability for the different methods (FIC, FLD, FEDin, FEDheat) for each measurement location and test.
- Appendix 3: images of the tests.

Figure 3.2 Start test

Figure 3.3 After three minutes the desk starts to burn due to heat radiation

Figure 3.4 After four minutes, burning droplets fall to the floor, desk, monitor and desk chair, allowing the fire to spread

Figure 3.5 After five minutes, more burning droplets fall down causing the armchair to burn

Figure 3.6 After eight minutes, the office is completely on fire

Figure 3.7 Office after the test

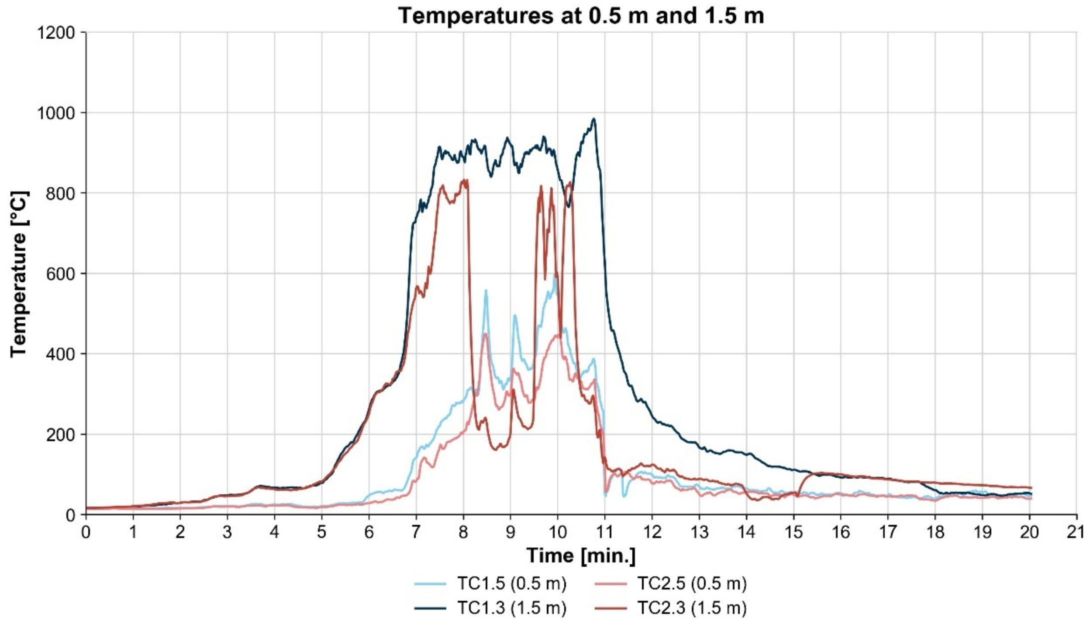

Figure 3.8 Temperatures at 0.5 and 1.5 m height [°C] for test 3

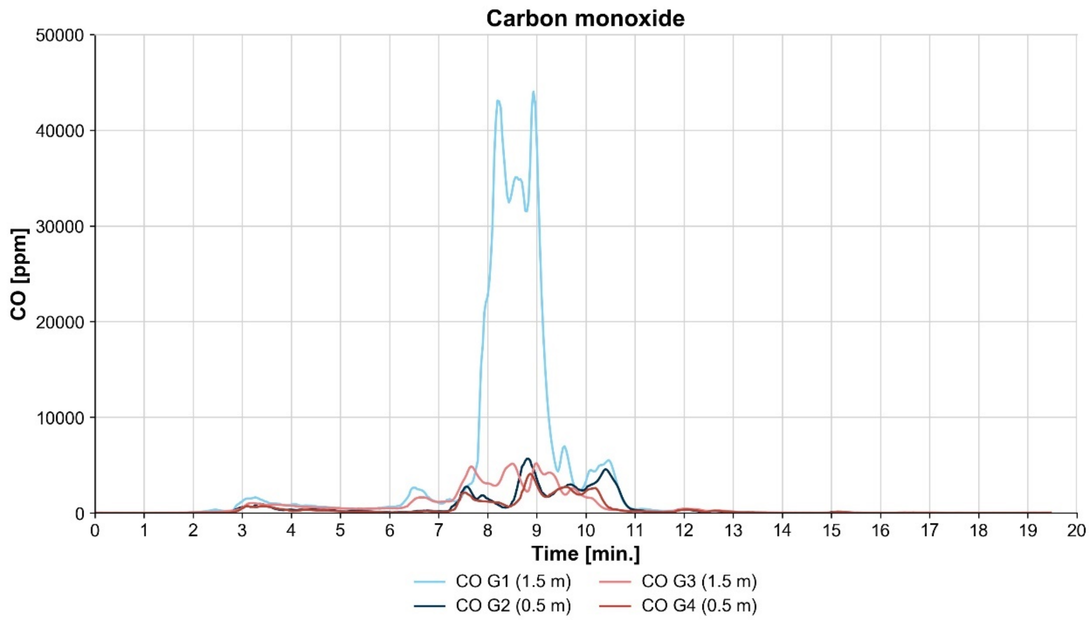

Figure 3.9 Carbon monoxide concentration at 4 locations [ppm] for test 3

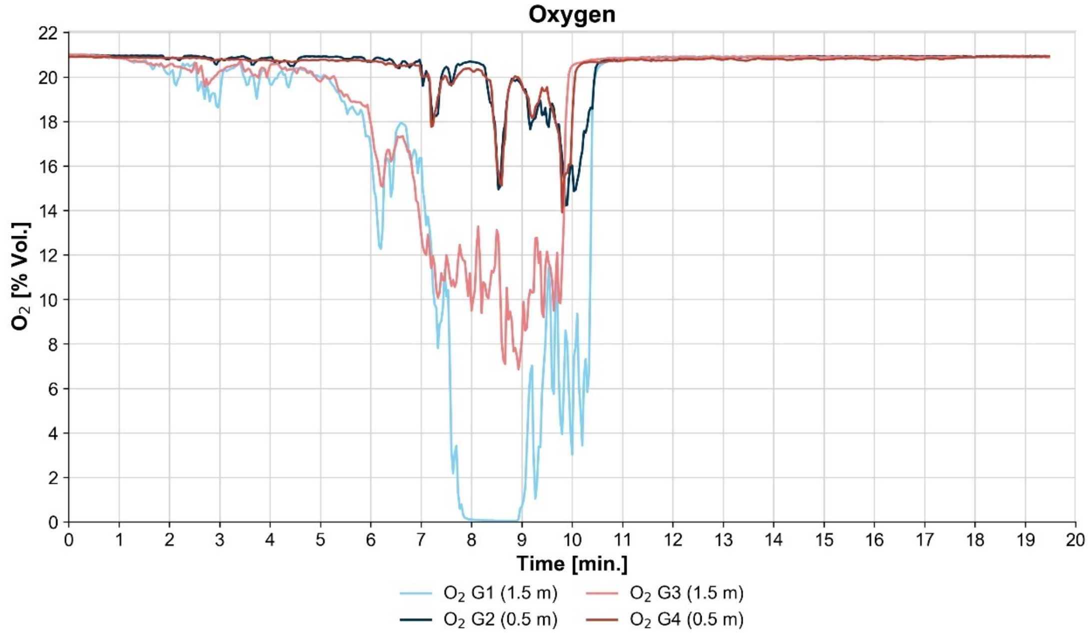

Figure 3.10 Oxygen concentration at 4 locations [% vol.] for test 3

Table 3.1 Times for the possibility of escape and survivability (in minutes) for test 3

Height												
0.5 m	< 5	5	6	6	< 6	6	6	6	< 6	6	7	7
1.5 m	< 5	5	5	6	< 6	6	6	6	< 6	6	6	7

Analysis

A fire in the cables propagates within a few minutes to other parts of the office. The following events regarding the propagation of the fire occurred during the test:

> 3:00 min: The fire propagates to the nearby desk and monitor cable because of the heat radiation.

> 3:10 min: Burning droplets fall on the carpet and the carpet starts burning.

> 3:40 min: Burning droplets fall on the desk chair, monitor and desk, causing the desk chair and monitor to catch fire.

> 4:20 min: Burning droplets fall on the armchair which causes the armchair to start burning.

> 7 – 8 minutes: Flashover, all the burnable objects in the room are completely involved in the fire.

> 11 minutes: The fire is suppressed with water in order to prevent damage to the fire room and measuring equipment.

The propagation of the fire is also visible in the temperature graph. The temperature rises to more than 300 °C after 3,5 minutes. After 5 minutes the temperature starts to increase and reaches a temperature of around 900 °C after 7 minutes. When the fire is suppressed, the temperature decreases to less than 200 °C within 2 minutes. The carbon monoxide concentration in the room is generally lower than 5000 ppm, but a peak concentration higher than 40.000 ppm was measured. The peak NO_x concentration is more than 1000 ppm and the minimal oxygen concentration is almost 0 volume %. This resulted in an impaired escape after 5 – 6 minutes and a life threatening and fatal situation after 5 – 7 minutes (dependent on the vulnerability of the group and the measurement height).

Heat was the first factor that caused an *impaired* escape in most situations. However, for the (highly) vulnerable group at a height of 1,5 meter the irritant gases were the first to cause an impaired escape. Visibility, which was not measured in the test, might have caused an impaired escape at an earlier point in time than the heat or irritant gases, especially at a height of 1,5 meter.

Heat was the first factor that caused a *life-threatening* situation in most situations, but again, for the highly vulnerable group at a height of 1,5 meters the asphyxiant gases were the first to cause a life-threatening situation. For the other groups and heights, the asphyxiant gases also caused a life-threatening situation in most cases within a few minutes after the heat led to a life-threatening situation.

The heat was also the first factor to cause a *fatal* situation. Within 20 seconds after reaching the limit value for a life-threatening situation, the limit value for a fatal situation was reached. At a height of 1,5 meter the asphyxiant gases caused a fatal situation, after this situation was already reached because of the heat. At a height of 0,5 meter the asphyxiant gases did not reach the limit value for a fatal situation for every group at every measurement location. At this height, plenty of fresh air flowed in from the outside towards the fire; in a real building with a hallway connected to the room this will probably be different. The irritant gases did not reach the limit value for a fatal situation.

Both heat and irritant and asphyxiant gases play a role in the possibility to escape and the survivability. For the propagation of the fire it is not just heat radiation that plays a role, but also the falling of burning droplets. If the horizontal part of the cable duct would have been placed above a lowered ceiling, the effect of the burning droplets would have been different. In this test the fire was able to propagate from the cables to another object in the room in 3 minutes.

4 Conclusions

Research question 1:

What is the fire behaviour in a single room environment of high performance cables and basic performance cables when exposed to an ignition source of burning methanol?

With the high performance cables, a fire propagates slowly and reaches its maximum size after 10 minutes. The high performance cables only burn in the section where they are impinged by the flames from the ignition source. Further away from the ignition source, where the cables are exposed to less heat from the ignition source, the fire in the cables dies out.

With the basic performance cables, the fire starts to propagate fast after 1 minute and 30 seconds. The peak fire size is reached after 4 minutes and 32 seconds and the cables are completely burned away after 10 minutes. When the horizontal part of the basic performance cables is involved in the fire, multiple burning droplets fall onto the floor and keep on burning there. This could result in a secondary fire spreading inside a room. A falling of burning droplets was not detected during the test with the high performance cables.

Research question 2:

What is the probability of escape and survivability in a single room environment when only the cables are burning?

A fire in just the set of high or basis performance cables used in the experiments and with the door of the fire room open will not result in an impaired escape or a life-threatening situation. If the door of the fire room would have been closed, this might be different. With a closed door, irritant and asphyxiant gases can reach higher concentrations inside a confined space. Temperatures inside the container would probably also be higher with a closed door.

Research question 3:

How does a fire propagate and develop in an office environment with a fire starting in the basic performance cables?

The fire starts to develop and propagate over the cables. After 3 minutes heat radiation causes the fire to spread to the nearby desk. Seconds later burning droplets start falling. Within 1,5 minutes the droplets result in the fire to propagate to the carpet, the desk chair, the monitor and the armchair. All these objects burning simultaneously result in a flashover after 7 to 8 minutes.

Research question 4:

What is the probability of escape and survivability in an office environment with a fire starting in the basic performance cables?

A fire in just the set of basic cables with an open door of the fire room did not result in an impaired escape or a life-threatening situation. In an office environment a fire starting in the set of basic cables resulted in an impaired escape after 5 – 6 minutes and a life-threatening and fatal situation after 5 – 7 minutes (dependent on the vulnerability of the group and the measurement height). Both heat, irritant gases and asphyxiant gases play a role in the possibility to escape and survivability.

5 Discussion

In this chapter the limitations of this study are discussed. Generally and obviously, the results of this study are only valid for the configurations studied in the experiments and therefore cannot be generalized, strictly speaking, except with plenty of caution.

There are some other limitations that should be mentioned:

> In order to compare the burning behaviour of the basic and high performance cables, only one configuration per type of cable was tested. In the office test, also only one configuration of basic performance cables was tested. It is unknown whether these type and configuration of cables are representative for other types or configurations of cables. It is also uncertain if the office set-up sued in the test is representative of other, real offices. There is also some uncertainty regarding the results of each test, because the tests per object were not repeated.

> The fire room has a floor space of about 14 m^2. Different room dimensions could lead to different results.

> The material of the enclosure (the steel container) influences the parameter heat. Accordingly, other materials (for instance brick) could lead to different results.

> The door of the container is larger than the average door.

> Although measurements took place at different levels (height) and different positions in the fire room, it is not certain if these measurements give a good representation of average conditions in the fire room at different heights. The measurements may reflect local circumstances.

> Although ignition sources were chosen and placed with care and the protocol was followed, there could be some (small) differences between tests.

> A limitation of the used methodology is that there are always some phenomena or uncertainties in the data that cannot be explained. The container is not a laboratory environment. The advantage of the chosen methodology however, is that a good impression of what can happen under ‘real life’ circumstances can be obtained.

> The limit values used to determine the possibility of escape and survivability are arbitrary, as has previously been mentioned. Other values could lead to different conclusions.

> In the experiments visibility was not measured. If visibility were measured during the experiments, this could have resulted in another outcome with respect to an impaired escape.

Considering these limitations, the results of these experiments regarding the fire behaviour, possibility of escape and survivability may differ from actual fires. However, this study provides a good impression of the fire behaviour of basic and high performance cables. It also gives a good impression of the pathways in which a fire in the basic performance cables spreads to other burnable objects. Therefore, the results of these tests are a good starting point to estimate the risks of high and basic performance cables in the built environment.

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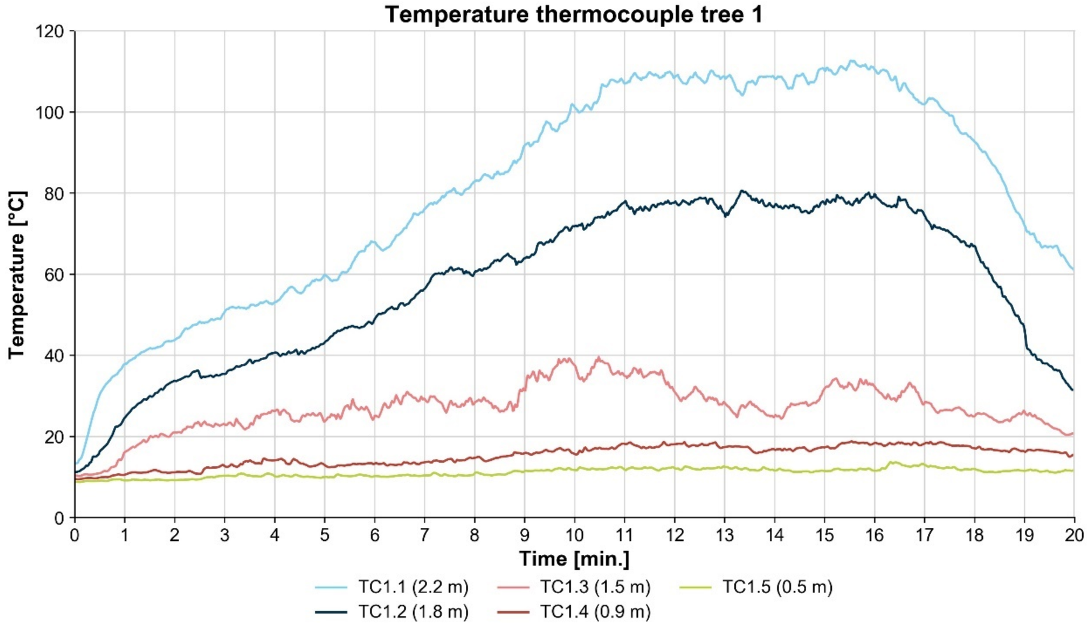
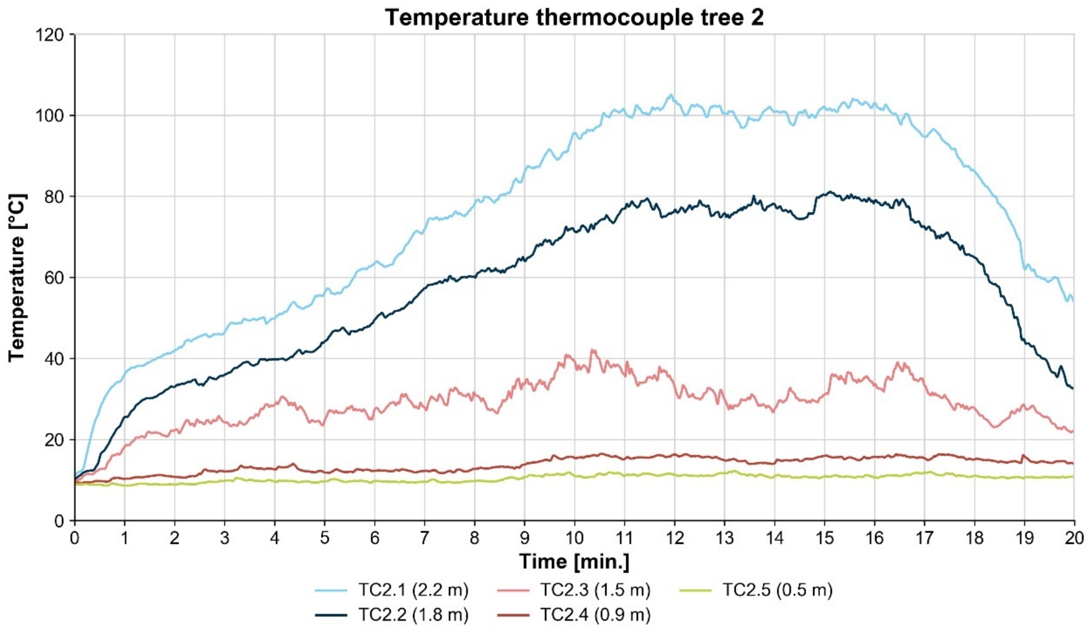
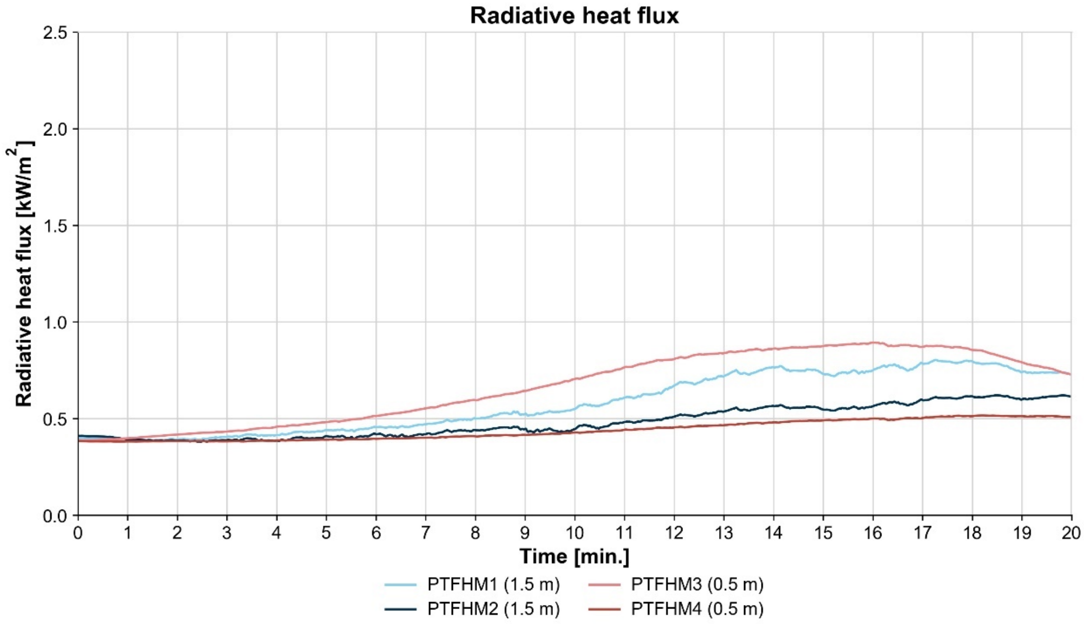
Appendix 1 Overview of measured data per sensor and test

Test high performance cables

Heat

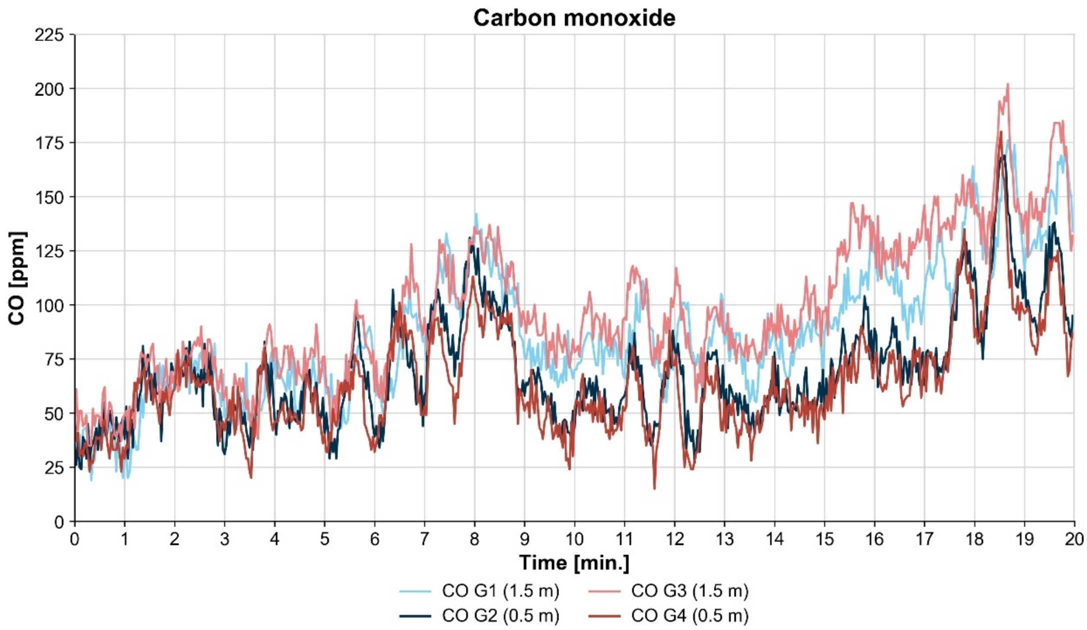




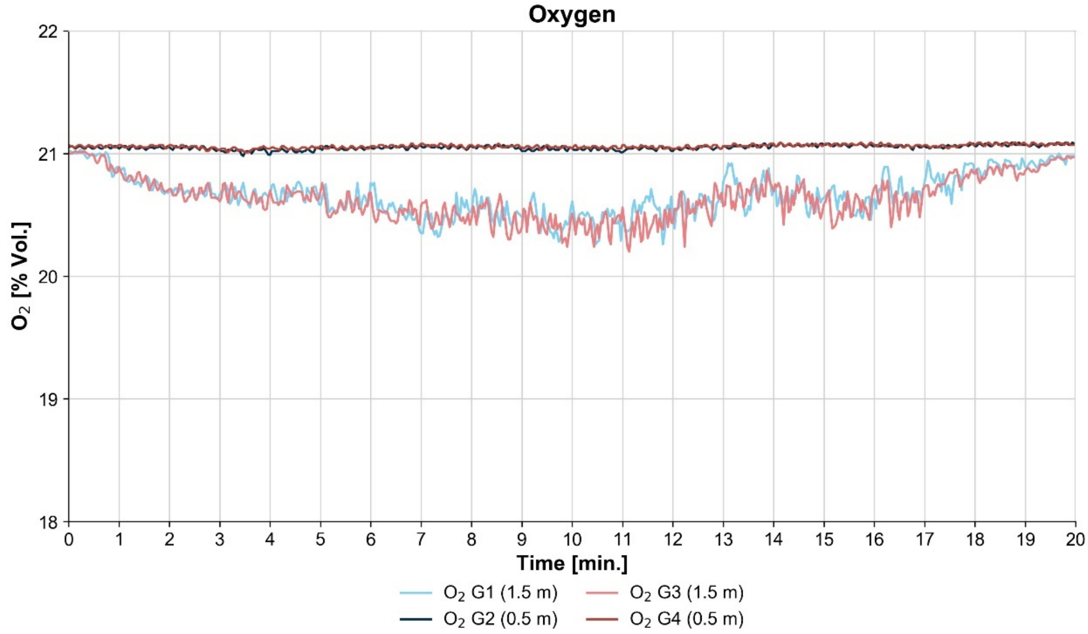


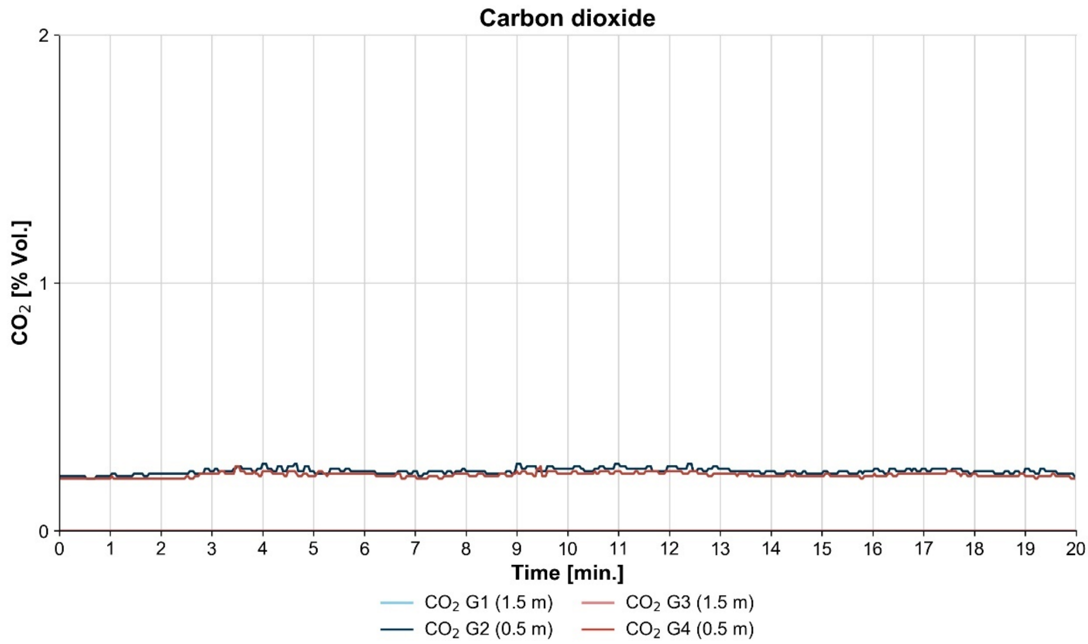
Radiative heat flux
Radiative heat flux [kW/m2]
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

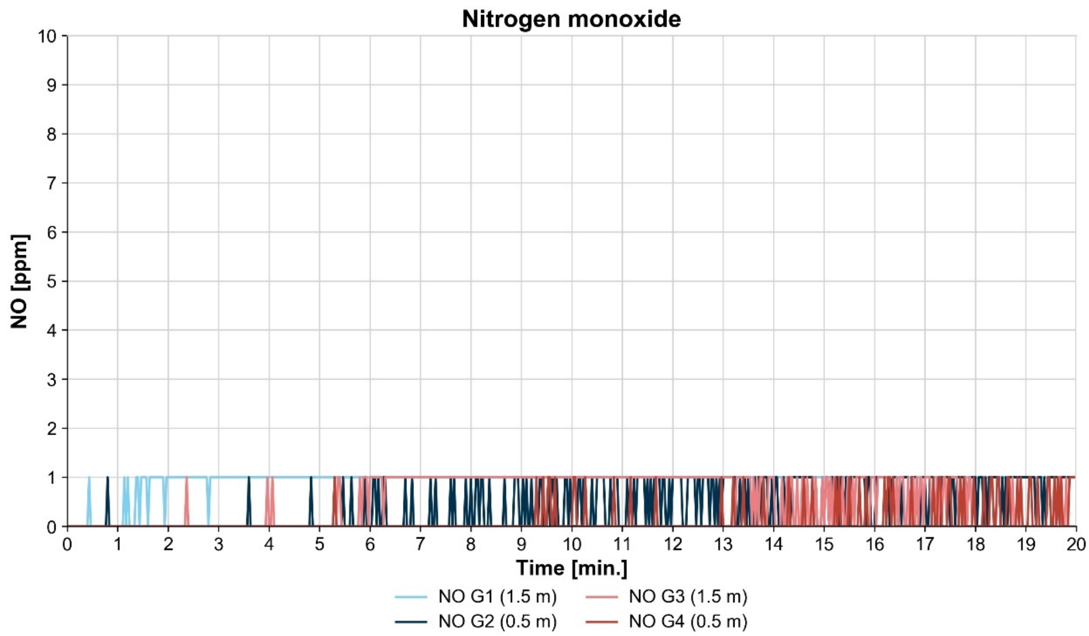
Gases

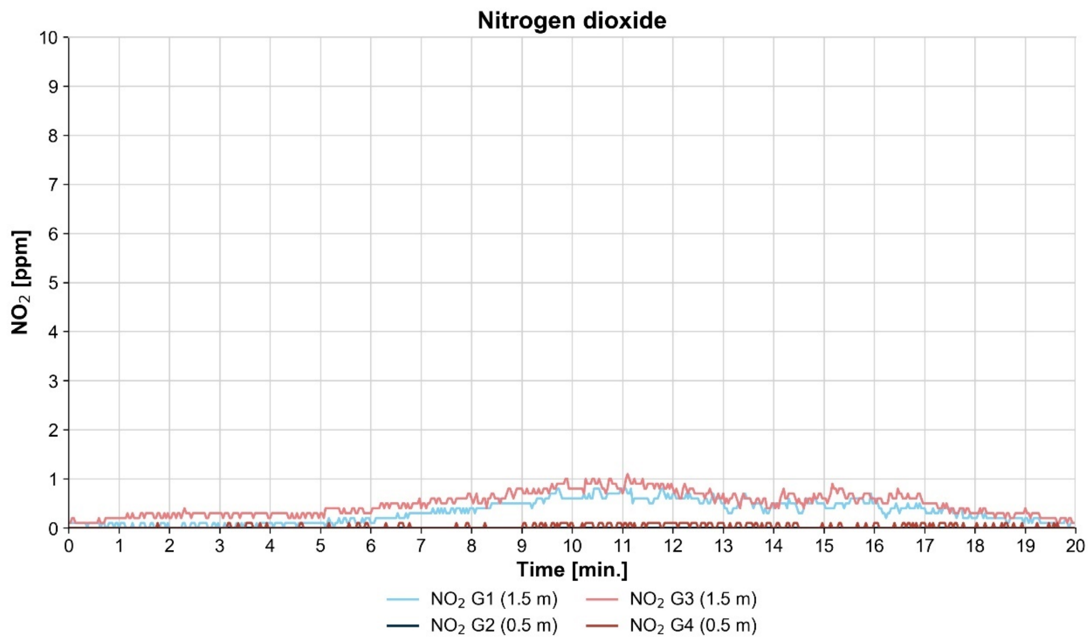


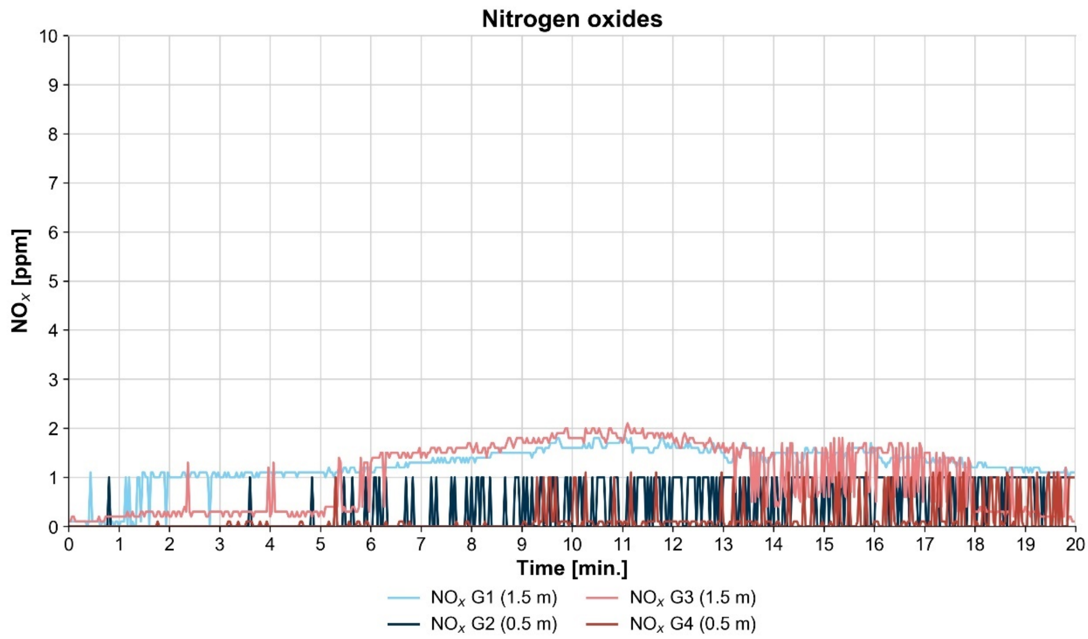
Carbon monoxide
CO [ppm]
225
200
175
150
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
22
21
20
19
18
O2 [% Vol.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
O2 G1 (1.5 m)
O2 G3 (1.5 m)
O2 G2 (0.5 m)
O2 G4 (0.5 m)


Carbon dioxide
2
1
0
CO2 [% Vol.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO2 G1 (1.5 m)
CO2 G3 (1.5 m)
CO2 G2 (0.5 m)
CO2 G4 (0.5 m)

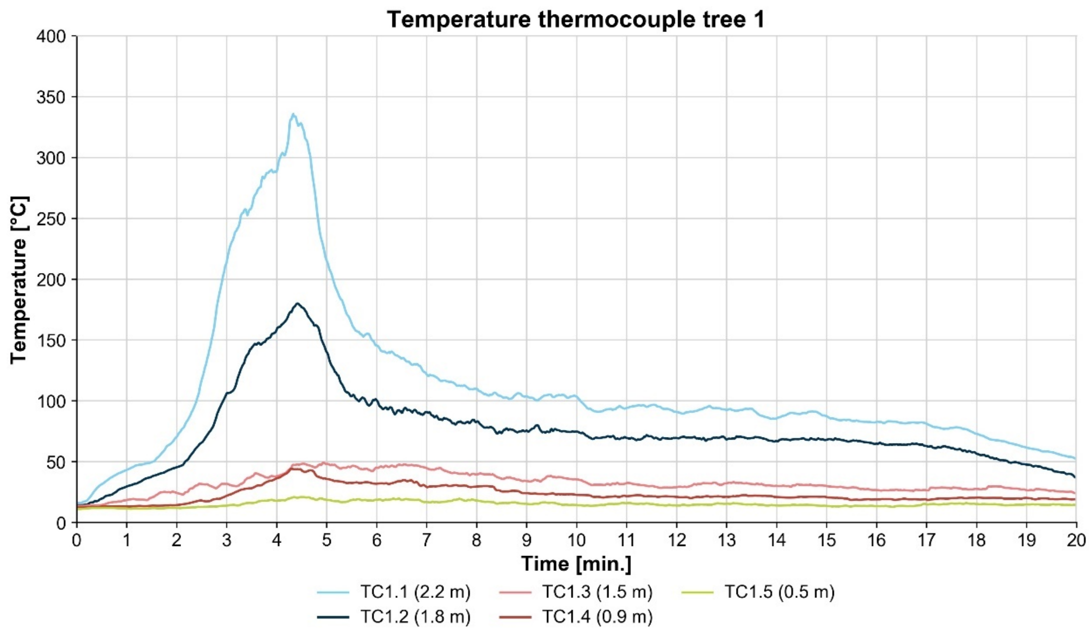

Nitrogen monoxide
NO [ppm]
Time [min.]
NO G1 (1.5 m)
NO G2 (0.5 m)
NO G3 (1.5 m)
NO G4 (0.5 m)

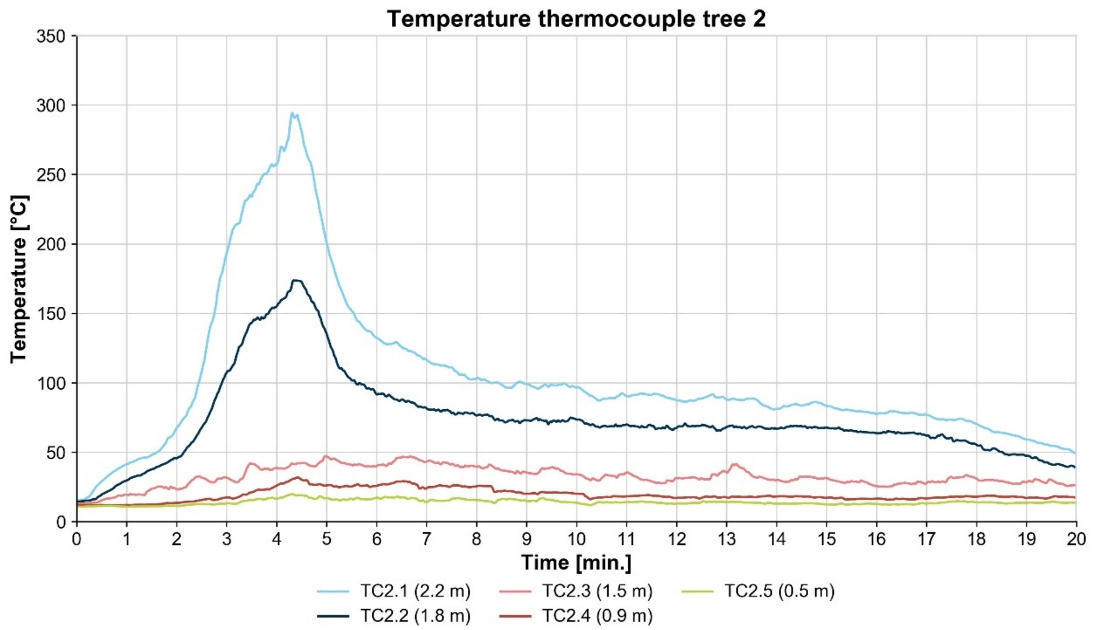

Nitrogen dioxide
NO_2 [ppm]
Time [min.]
NO_2 G1 (1.5 m)
NO_2 G2 (0.5 m)
NO_2 G3 (1.5 m)
NO_2 G4 (0.5 m)

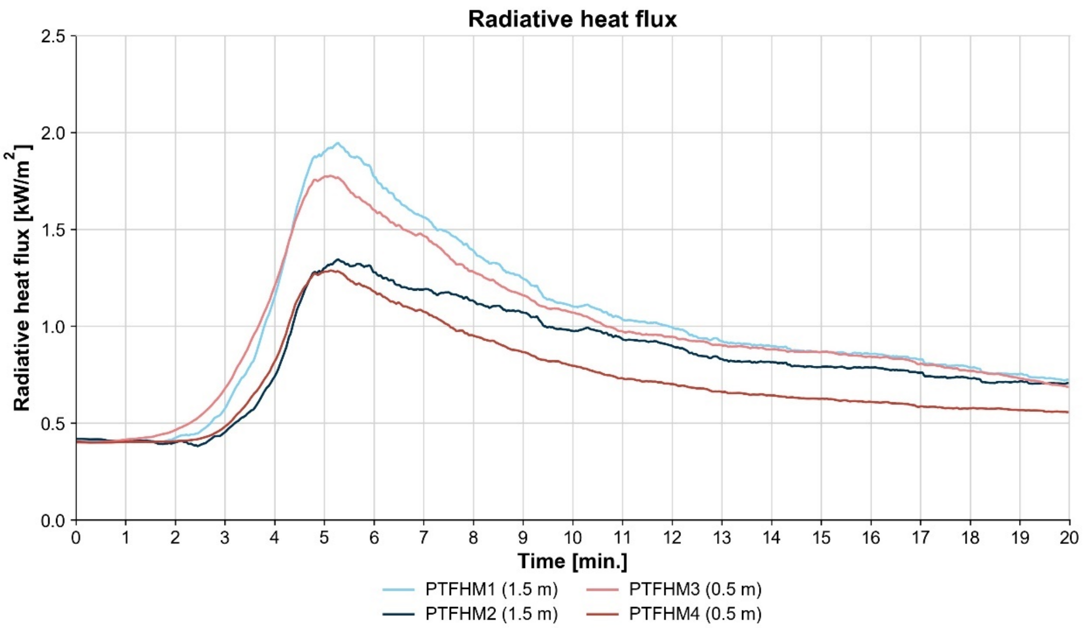


Test basic performance cables

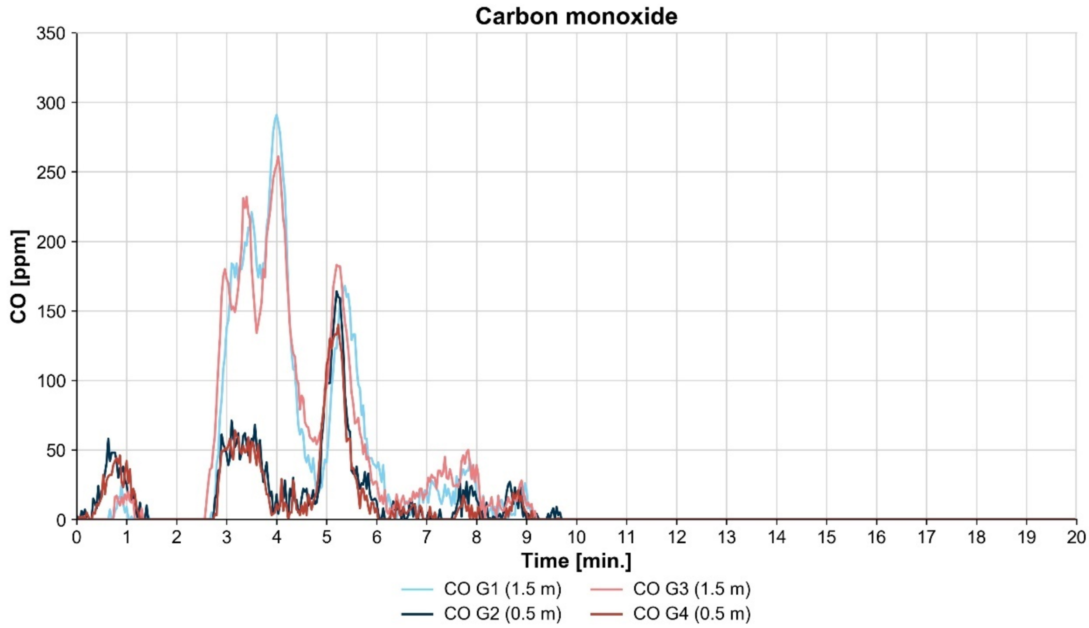
Heat



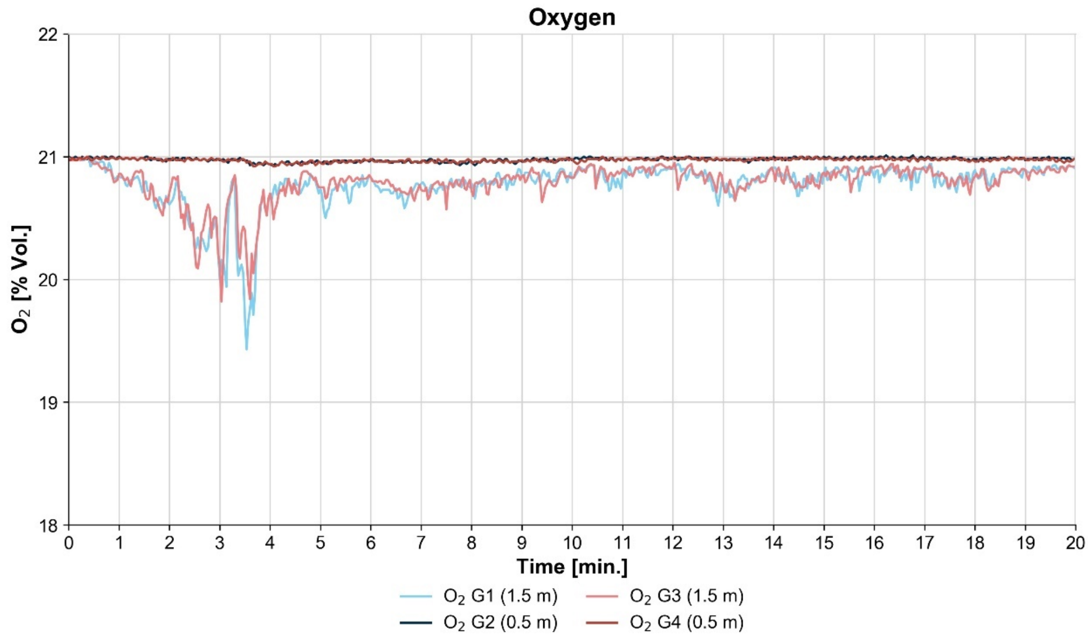

Temperature thermocouple tree 2
Temperature [°C]
Time [min.]
TC2.1 (2.2 m)
TC2.2 (1.8 m)
TC2.3 (1.5 m)
TC2.4 (0.9 m)
TC2.5 (0.5 m)


Radiative heat flux
Radiative heat flux [kW/m2]
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

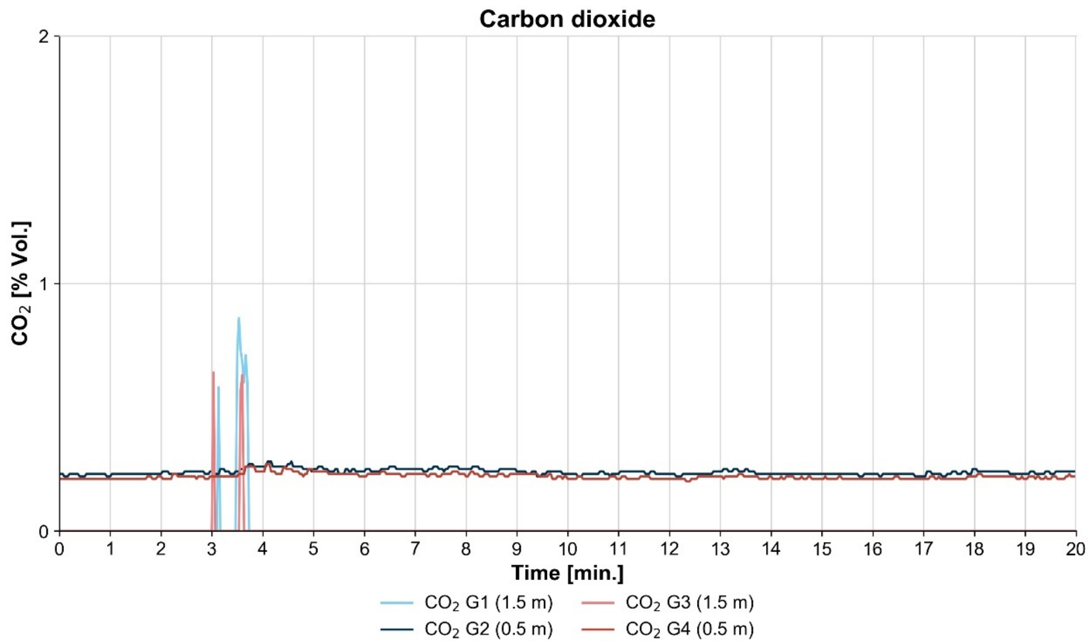
Gases



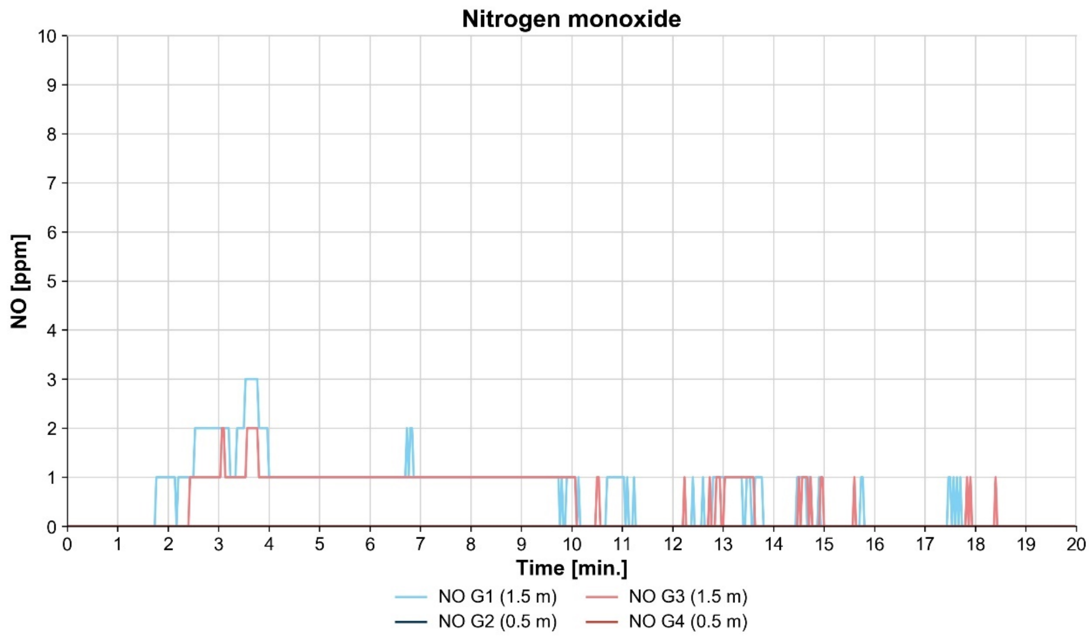
Carbon monoxide
CO [ppm]
350
300
250
200
150
100
50
0
Time [min.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
CO G1 (1.5 m)
CO G3 (1.5 m)
CO G2 (0.5 m)
CO G4 (0.5 m)



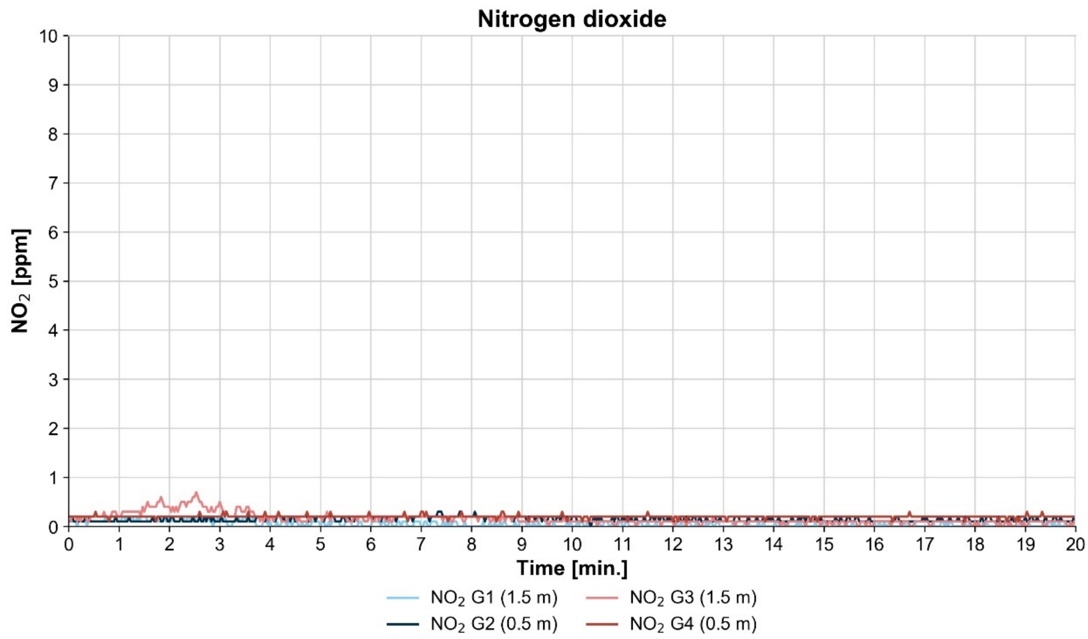
Oxygen
O_2 [% Vol.]
22
21
20
19
18
Time [min.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
O_2 G1 (1.5 m)
O_2 G3 (1.5 m)
O_2 G2 (0.5 m)
O_2 G4 (0.5 m)



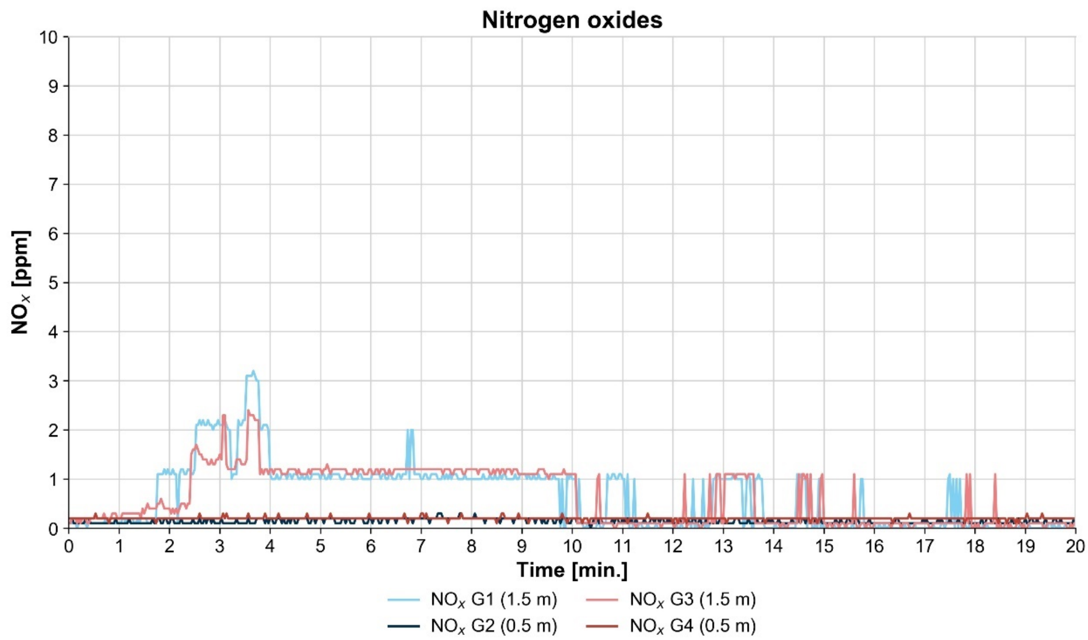
Carbon dioxide
CO2 [% Vol.]
Time [min.]
CO2 G1 (1.5 m)
CO2 G3 (1.5 m)
CO2 G2 (0.5 m)
CO2 G4 (0.5 m)



Nitrogen monoxide
NO [ppm]
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)



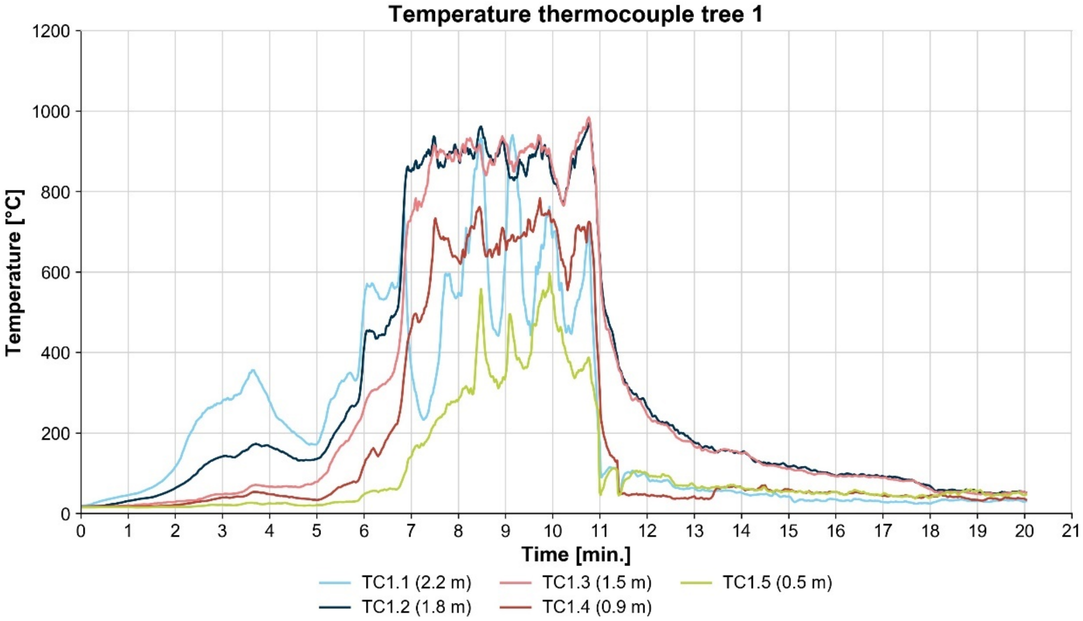
Nitrogen dioxide
NO2 [ppm]
Time [min.]
NO2 G1 (1.5 m)
NO2 G2 (0.5 m)
NO2 G3 (1.5 m)
NO2 G4 (0.5 m)

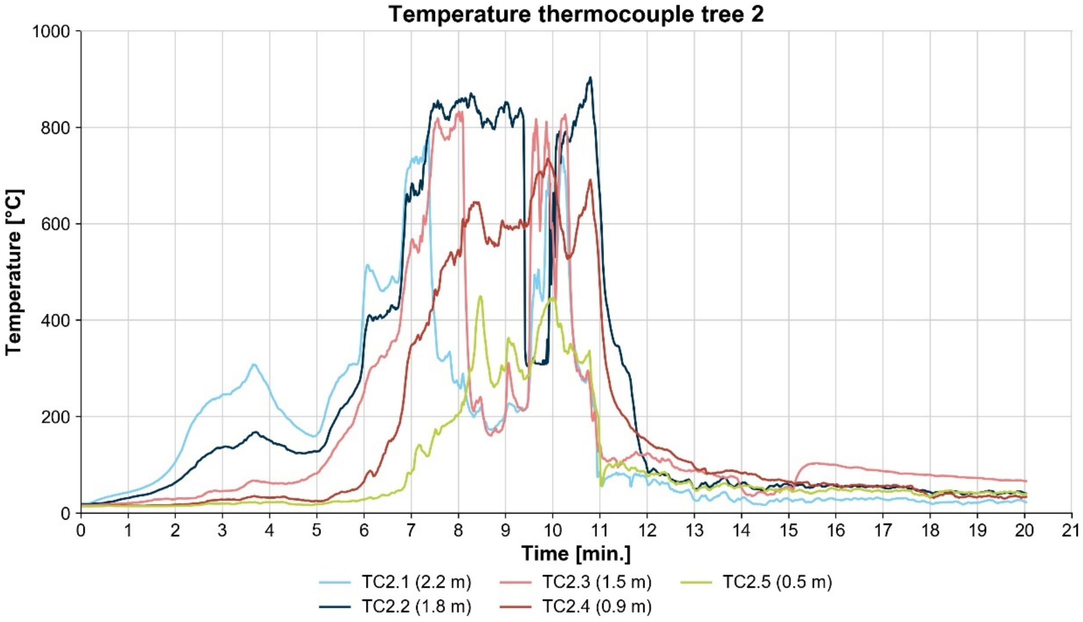


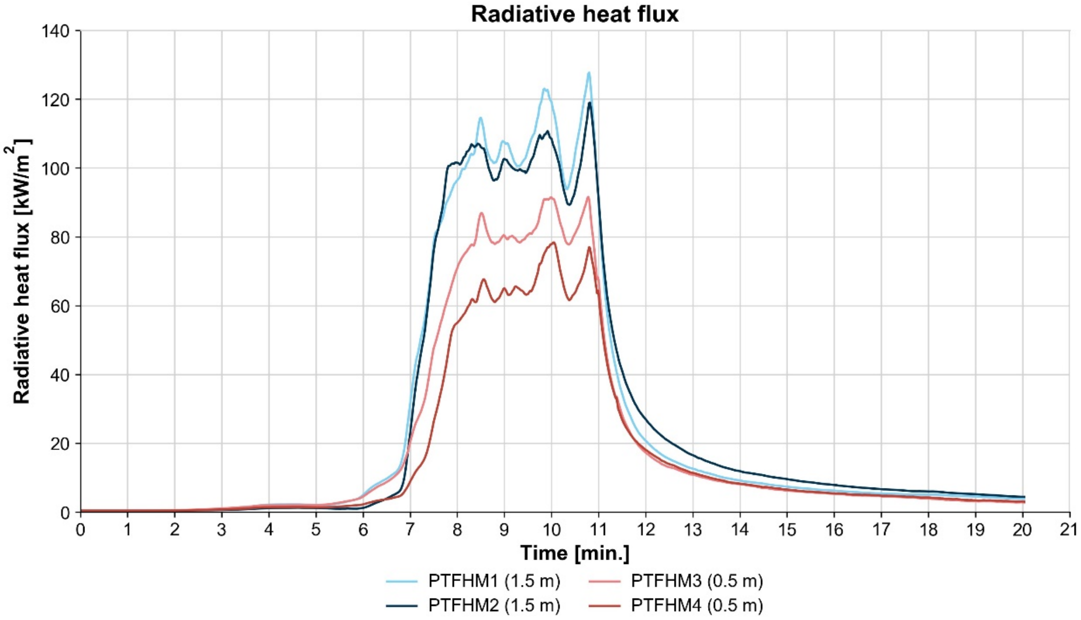
Nitrogen oxides
NOx [ppm]
Time [min.]
NOx G1 (1.5 m)
NOx G2 (0.5 m)
NOx G3 (1.5 m)
NOx G4 (0.5 m)

Test basic performance cables in an office environment

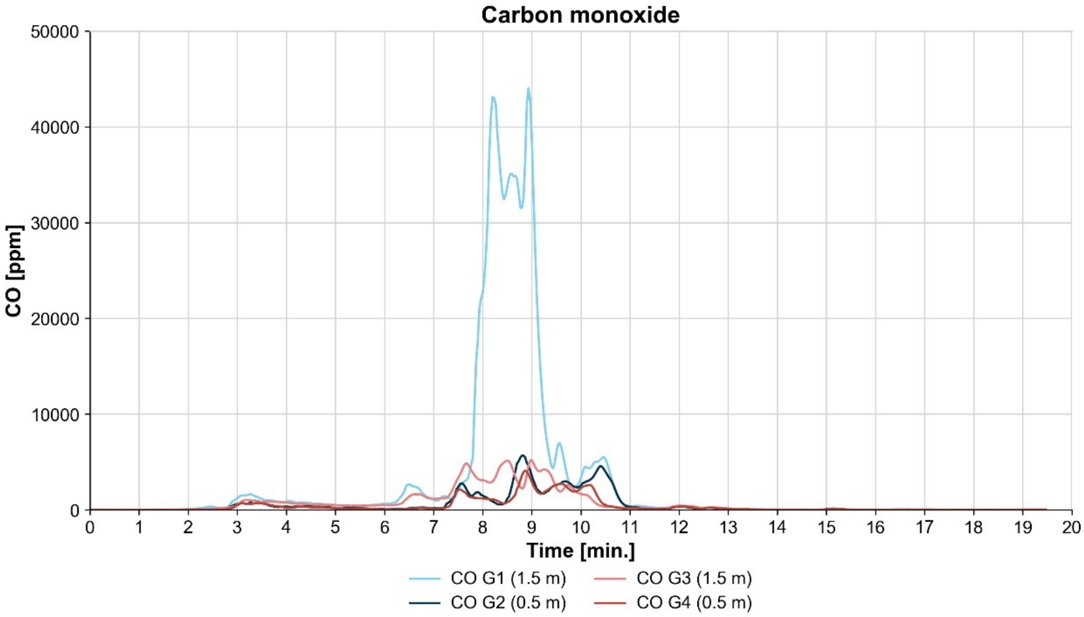
Heat

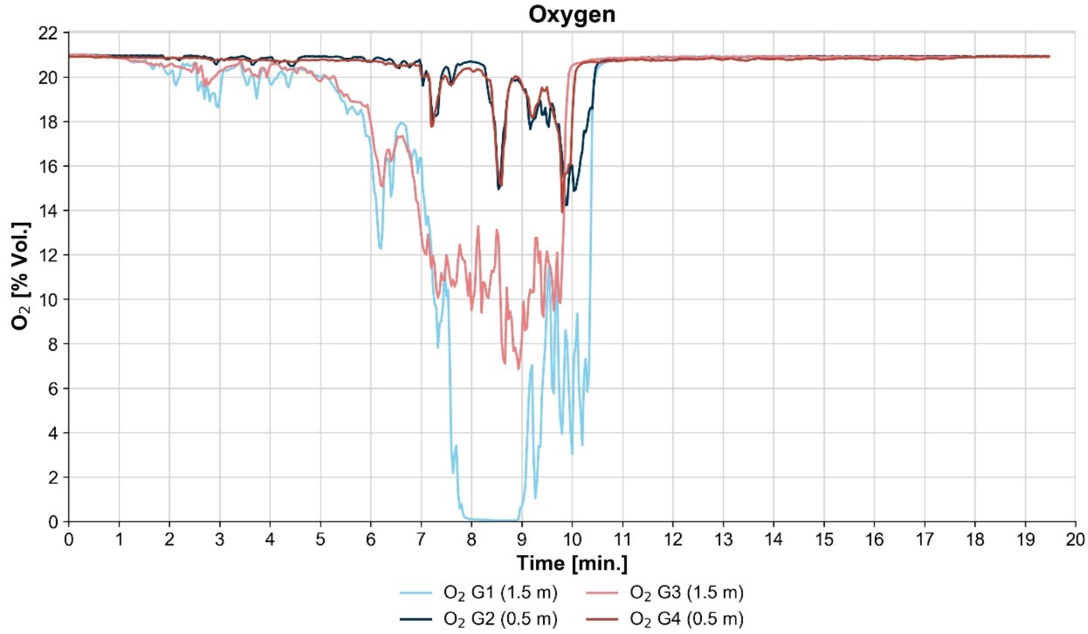


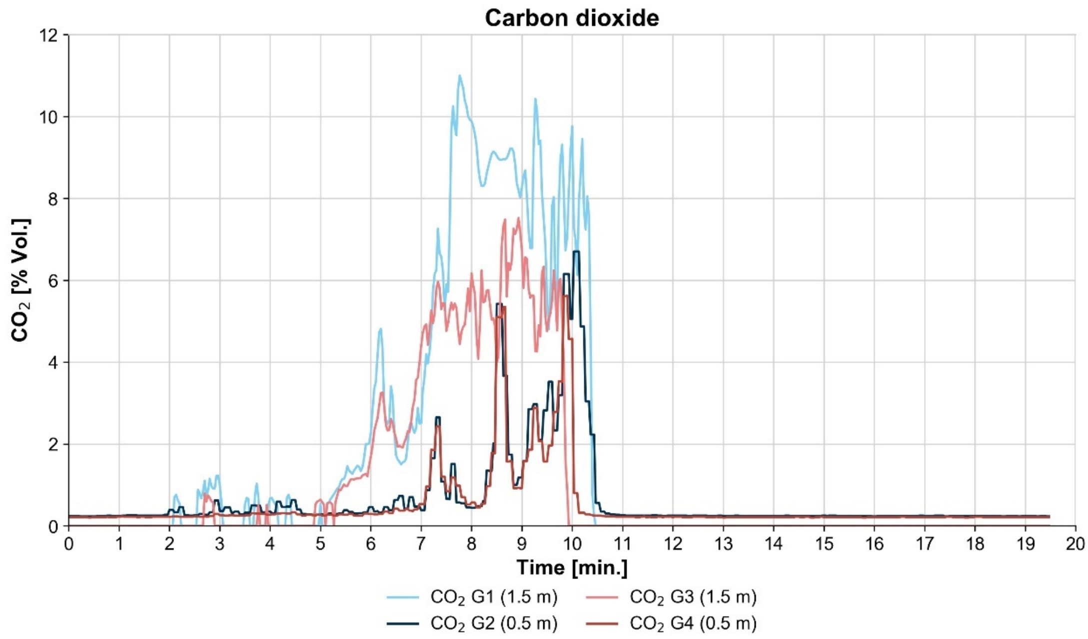


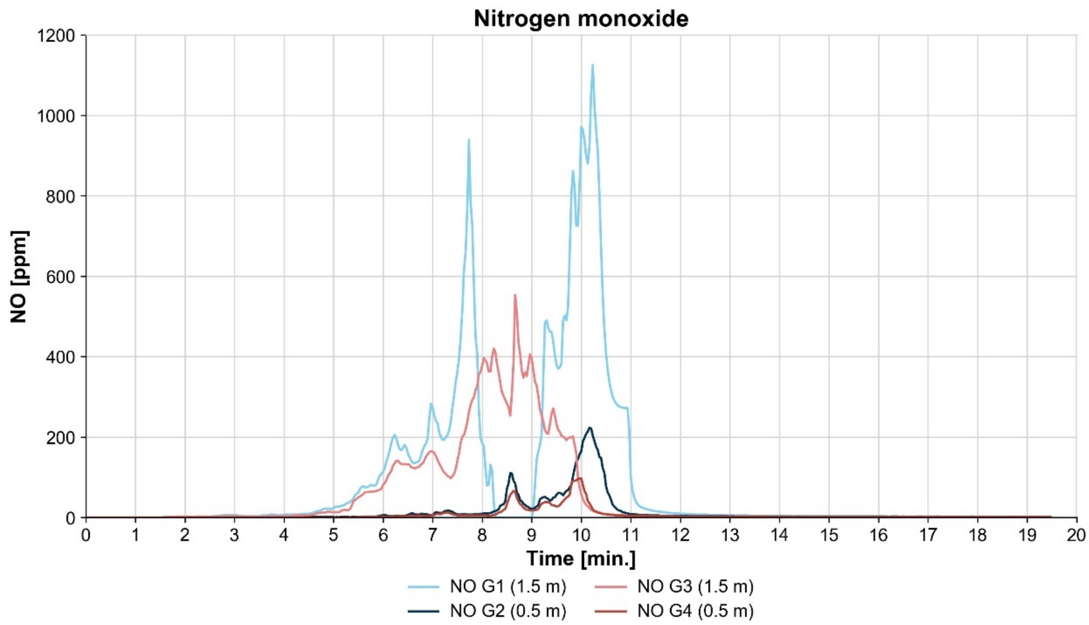

Radiative heat flux
Radiative heat flux [kW/m2]
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

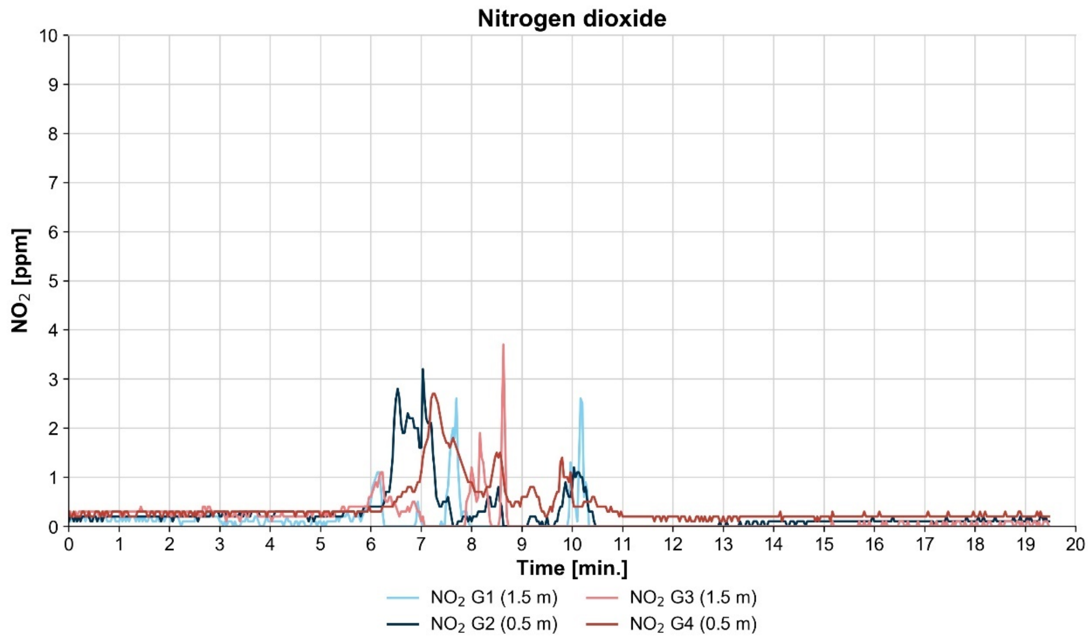
Gases

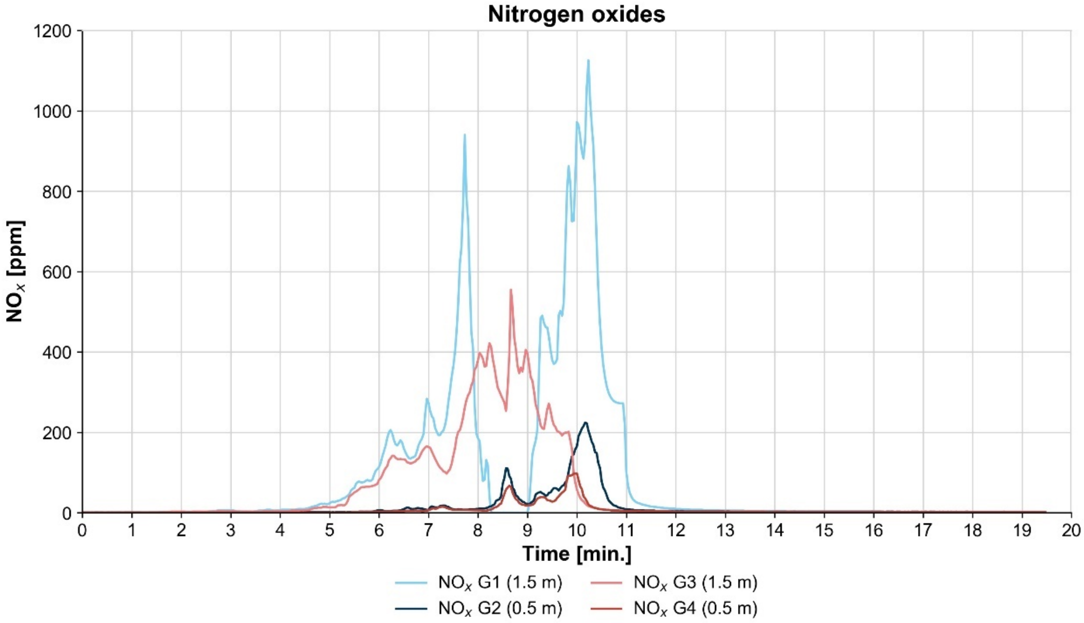

Carbon monoxide
CO [ppm]
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
O_2 [% Vol.]
Time [min.]
O_2 G1 (1.5 m)
O_2 G3 (1.5 m)
O_2 G2 (0.5 m)
O_2 G4 (0.5 m)


Carbon dioxide
CO_2 [% Vol.]
Time [min.]
CO_2 G1 (1.5 m)
CO_2 G3 (1.5 m)
CO_2 G2 (0.5 m)
CO_2 G4 (0.5 m)


Nitrogen monoxide
NO [ppm]
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)

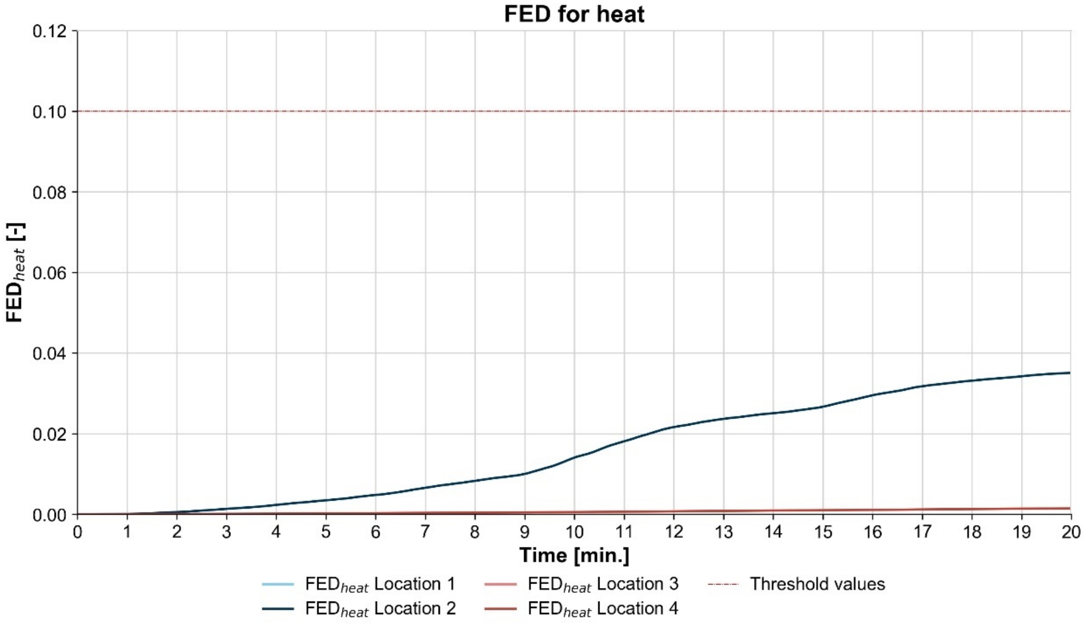

Nitrogen dioxide
NO2 [ppm]
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
NO2 G1 (1.5 m)
NO2 G3 (1.5 m)
NO2 G2 (0.5 m)
NO2 G4 (0.5 m)


Nitrogen oxides
1200
1000
800
600
400
200
0
NO_x [ppm]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
NO_x G1 (1.5 m)
NO_x G3 (1.5 m)
NO_x G2 (0.5 m)
NO_x G4 (0.5 m)

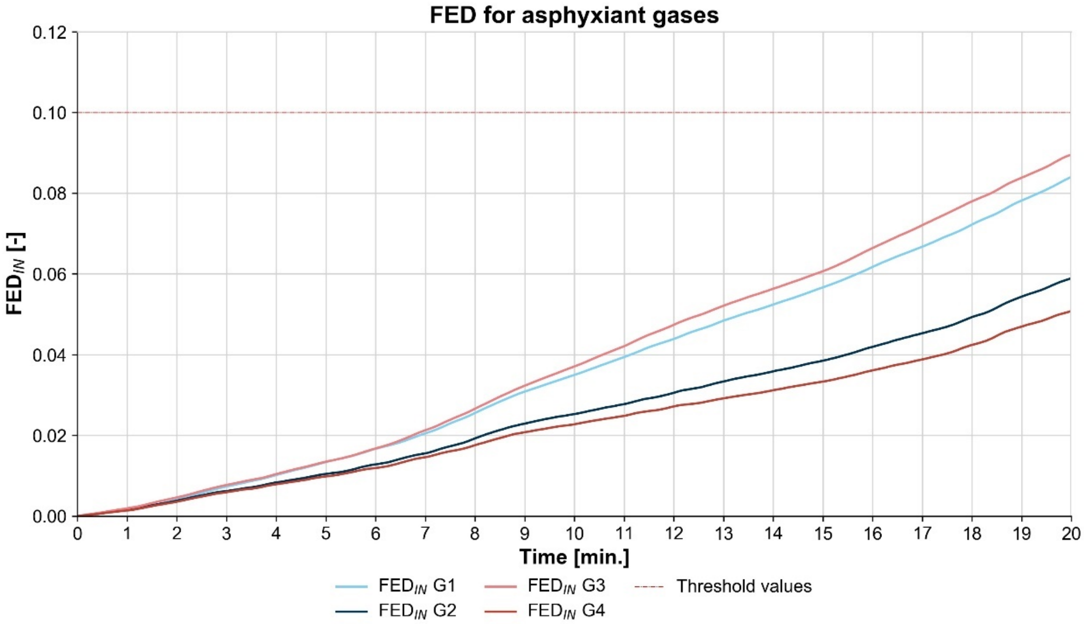
Appendix 2 Overview of the development of the possibility of escape and survivability for the different methods for each measurement location and test

Test high performance cables

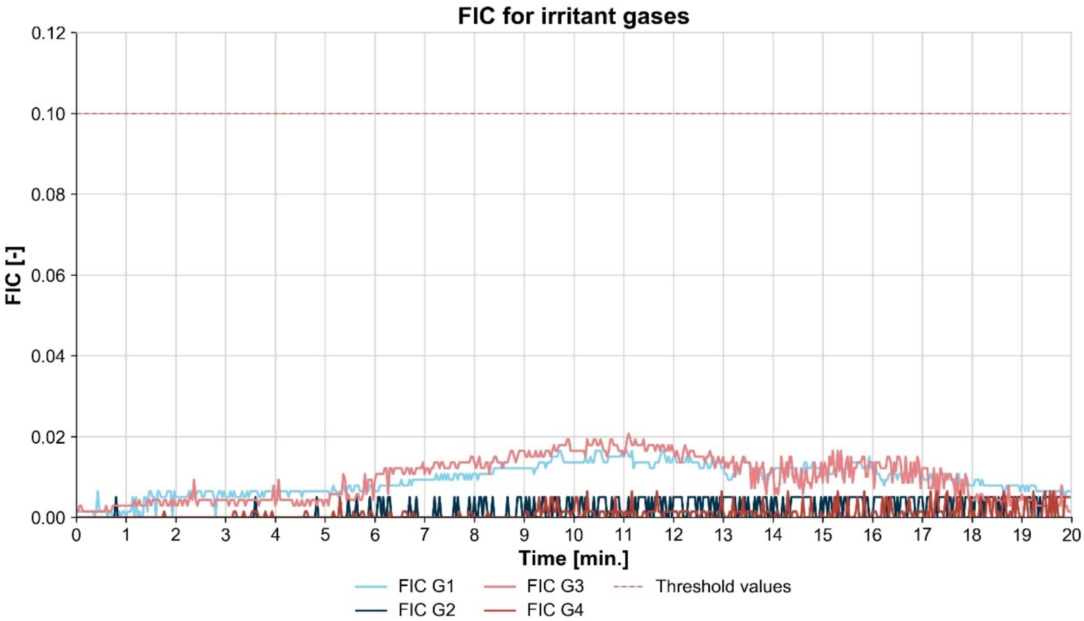
FED for heat



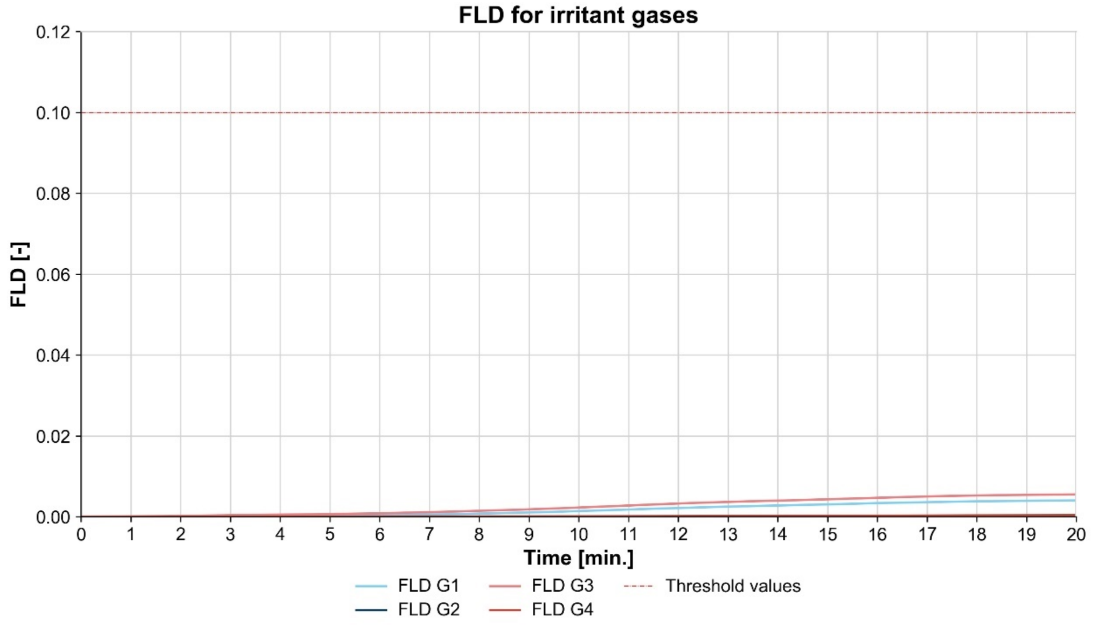
FED for asphyxiant gases



FIC for irritant gases

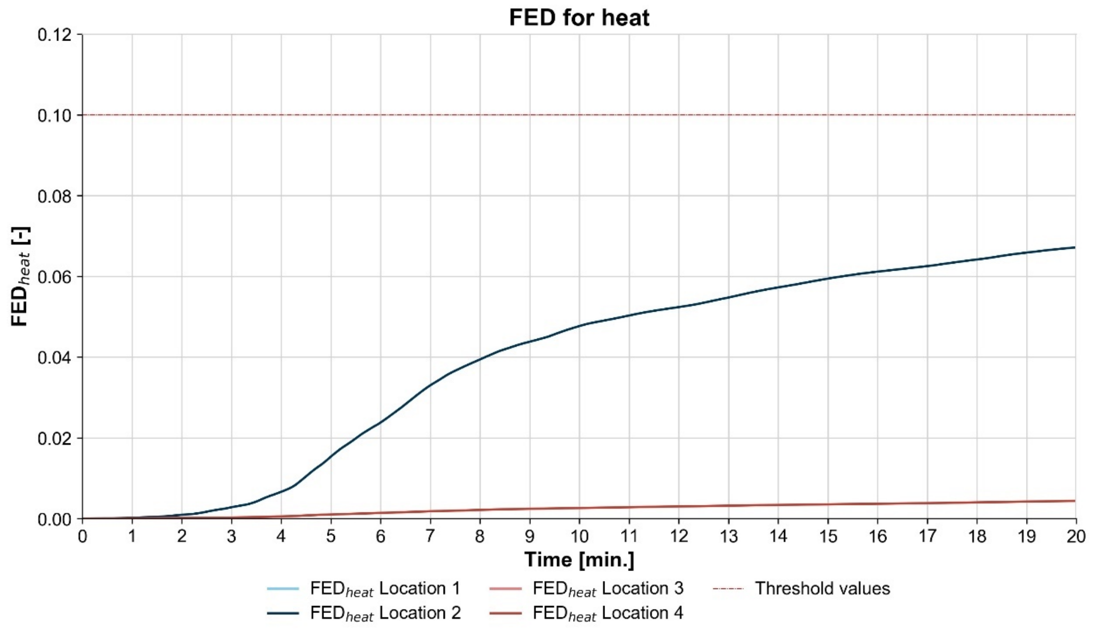


FLD for irritant gases

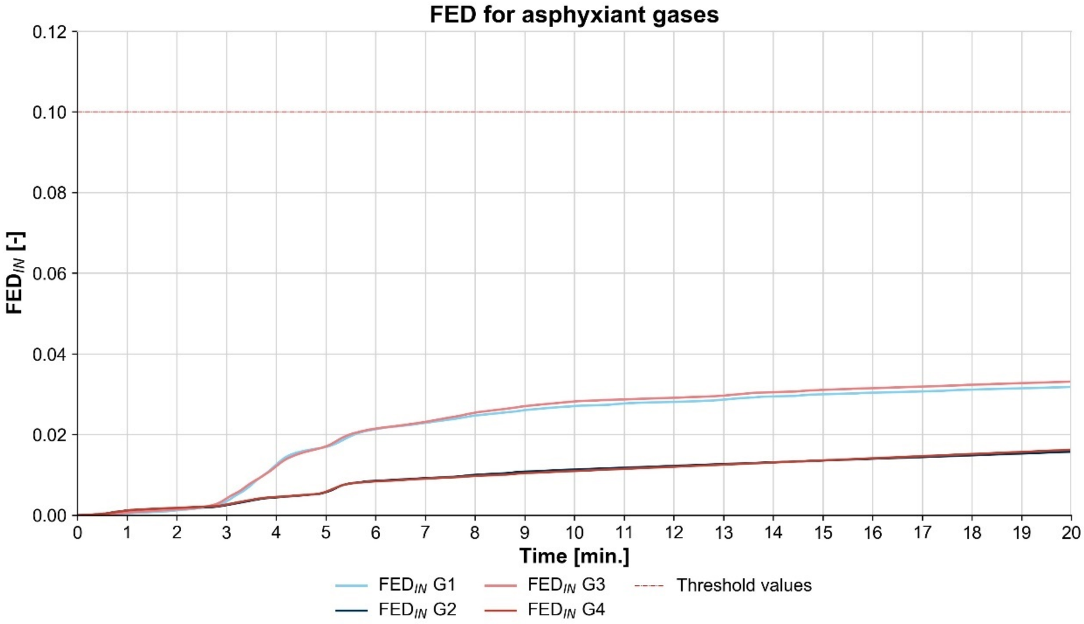


Test basic performance cables

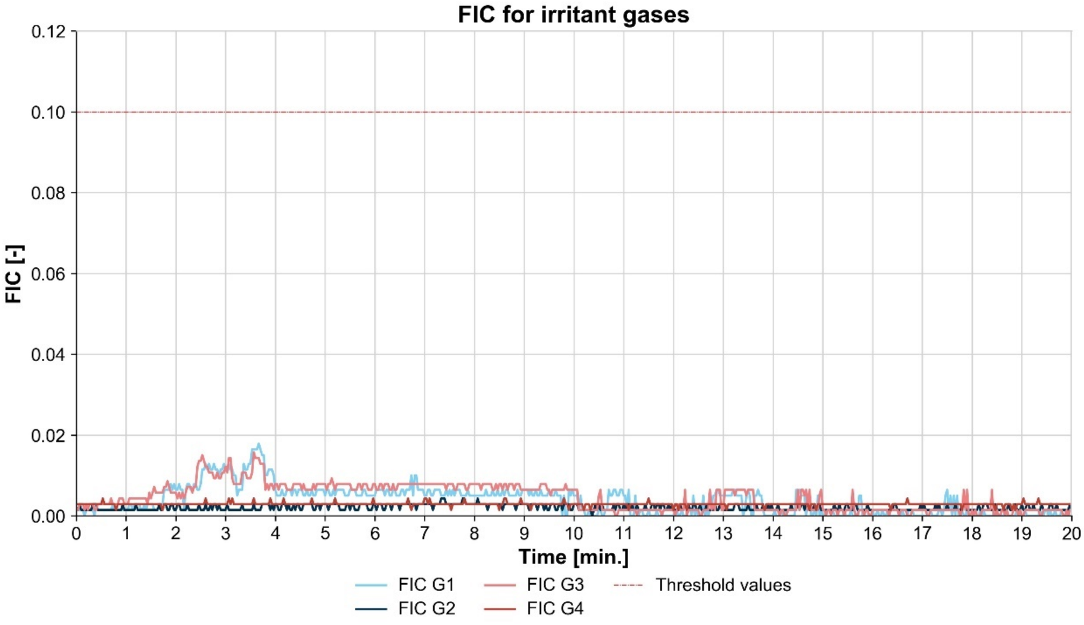
FED for heat



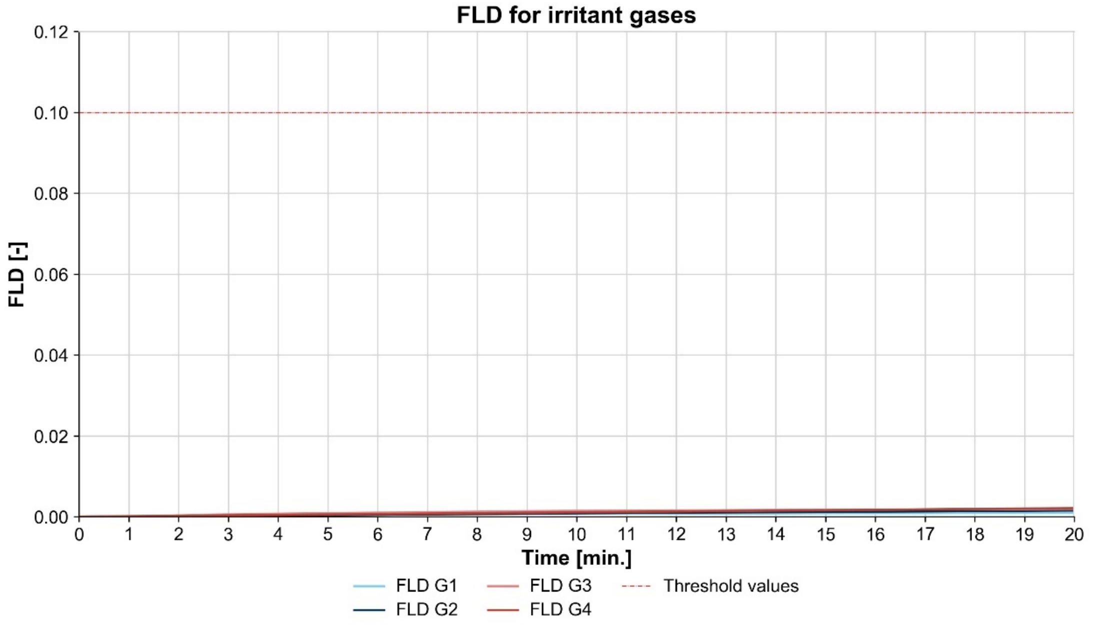
FED for asphyxiant gases



FIC for irritant gases

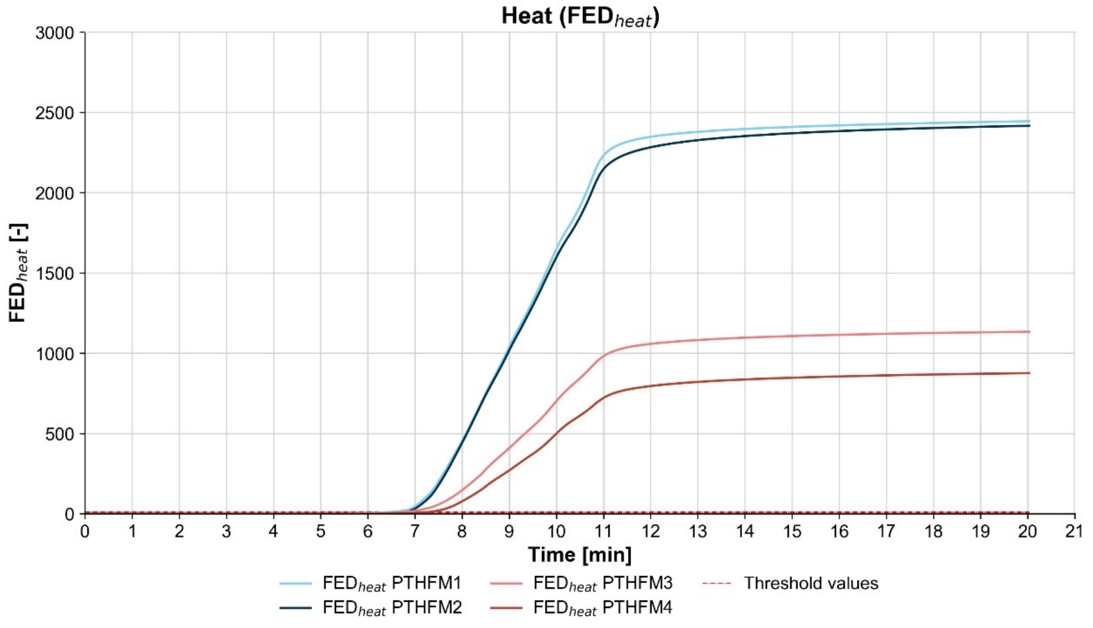


FLD for irritant gases

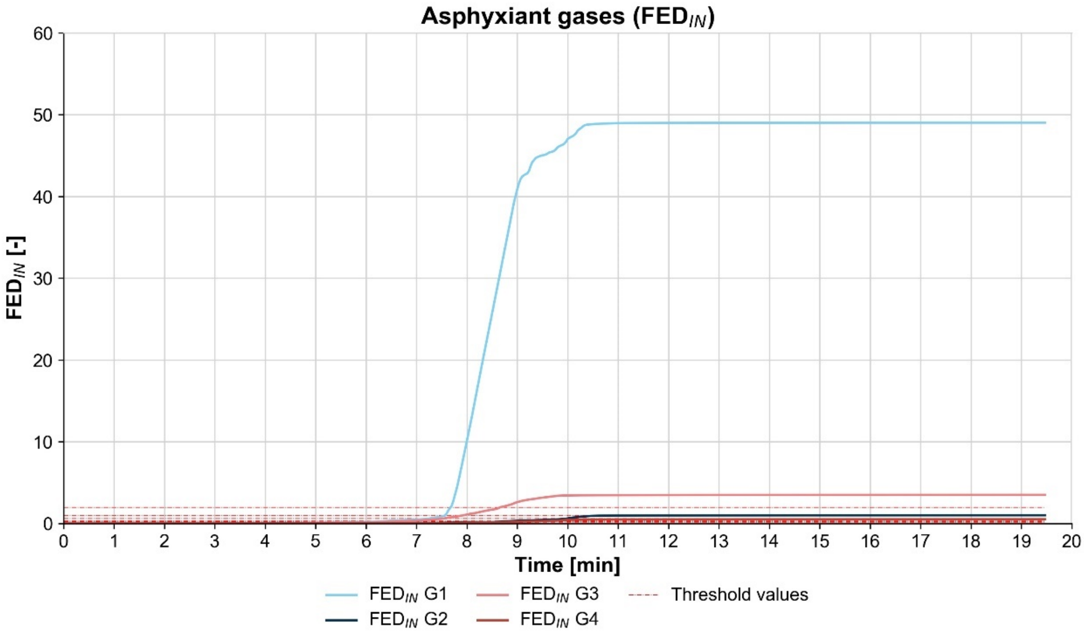


Test basic performance cables in an office environment

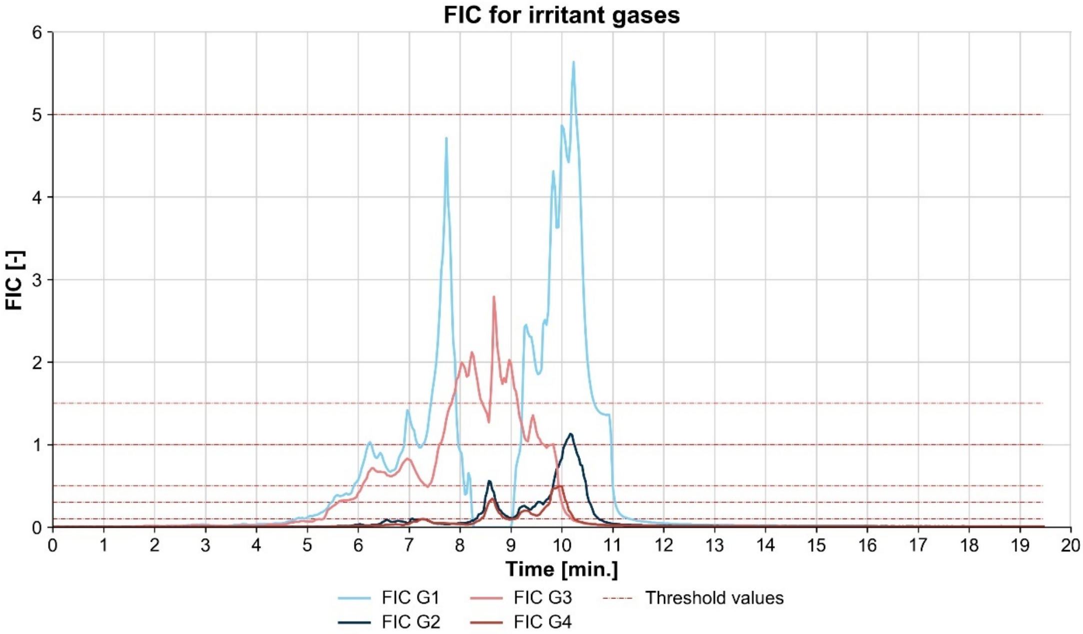
FED for heat



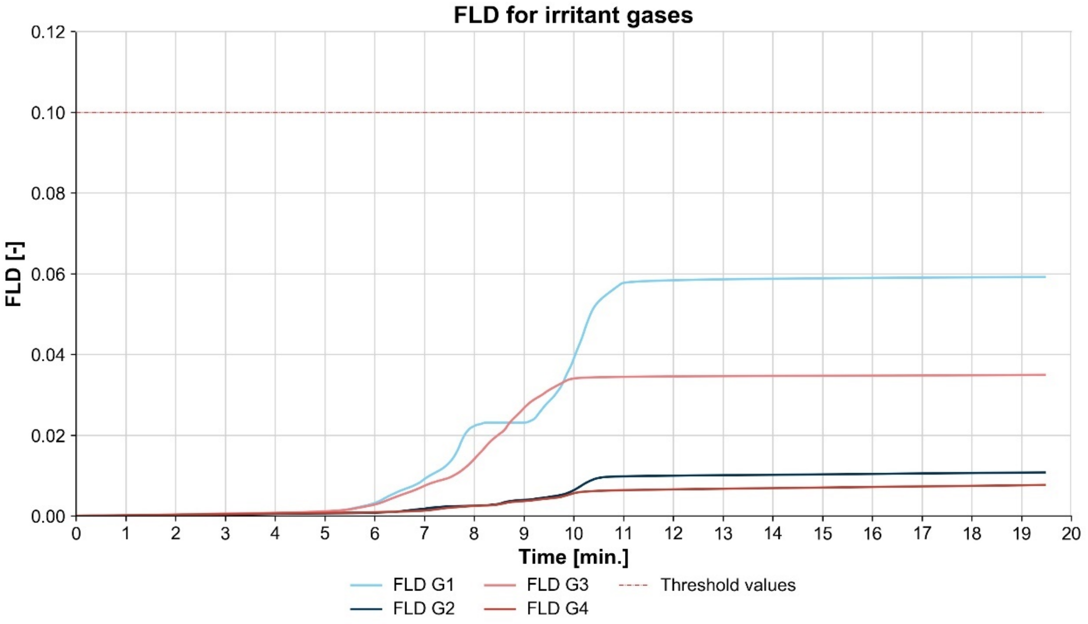
FED for asphyxiant gases



FIC for irritant gases

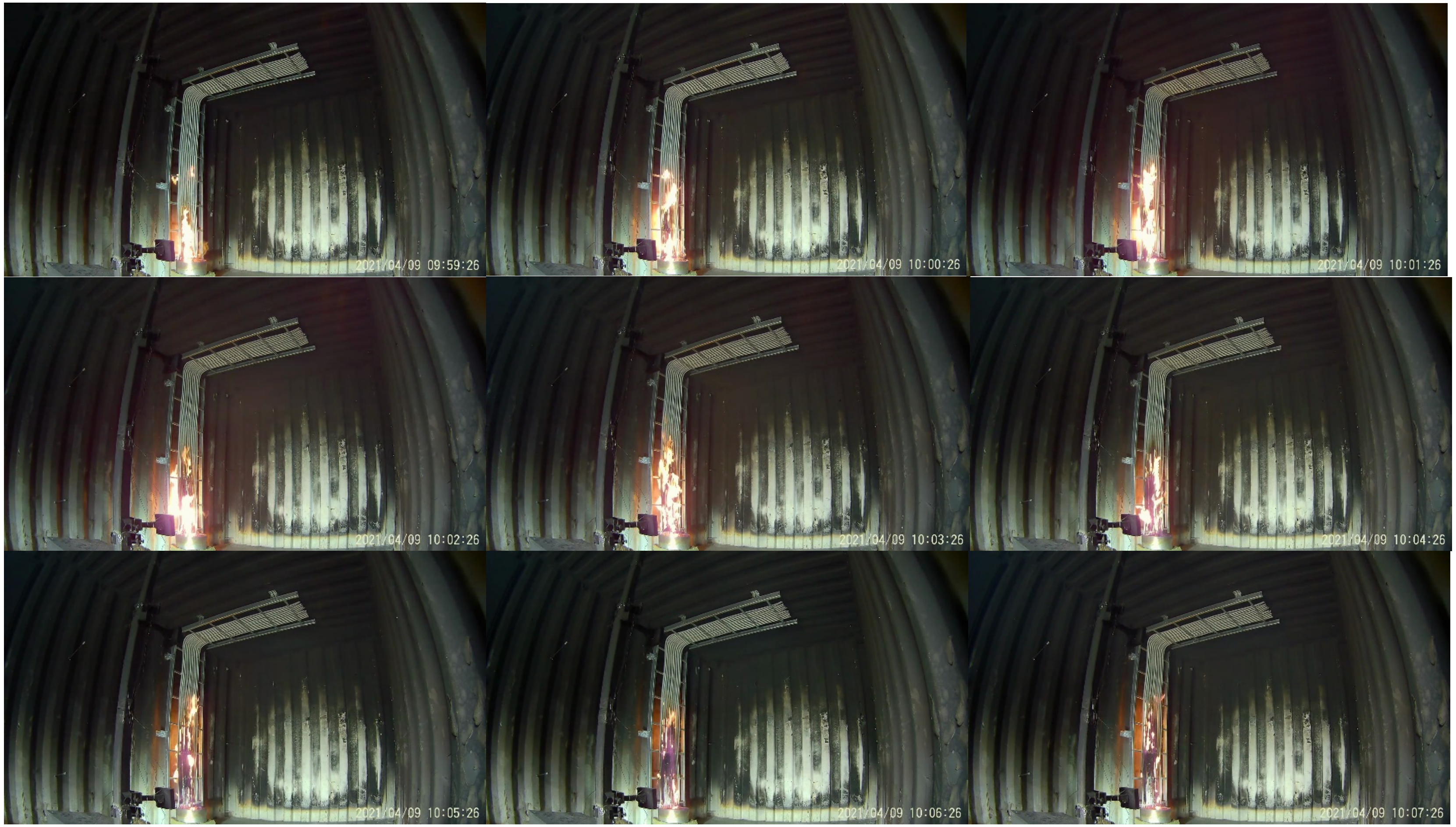


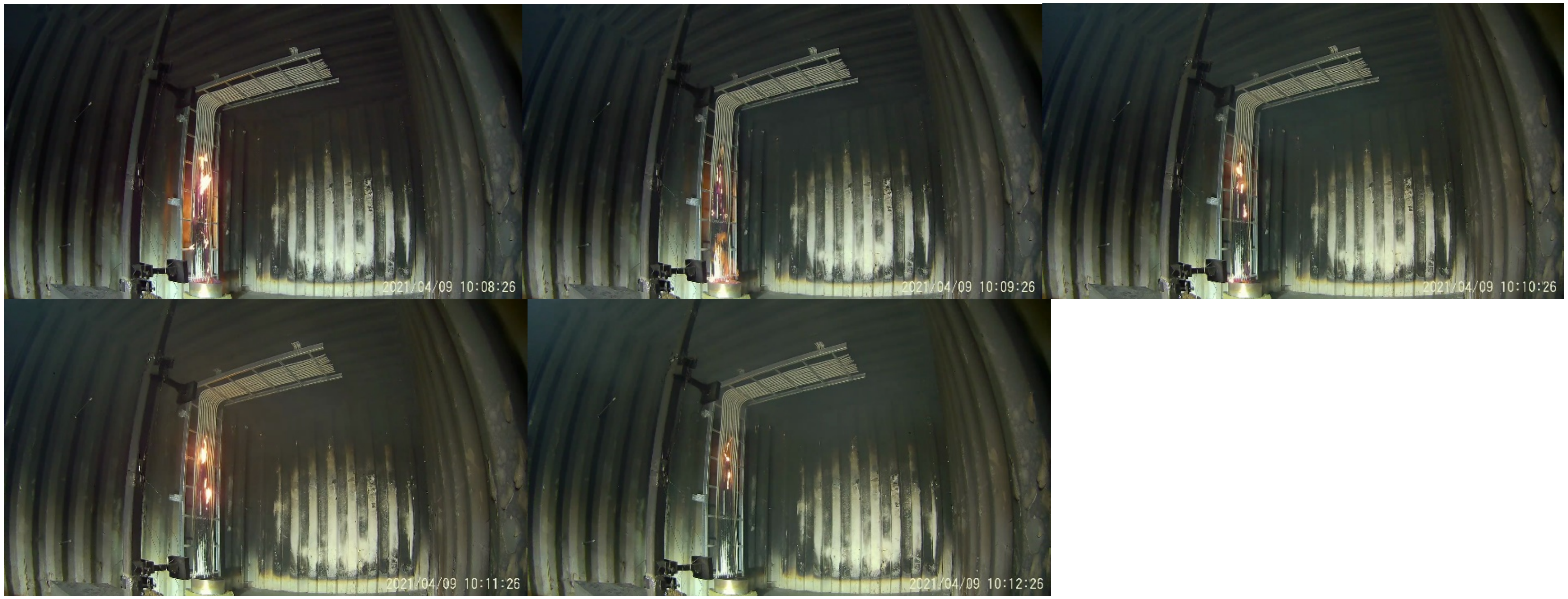
FLD for irritant gases



Appendix 3 Images of the tests

High performance cables (20 minutes, 1 photo every minute starting at t = 1 minute)


2021/04/09 09:59:26
2021/04/09 10:00:26
2021/04/09 10:01:26
2021/04/09 10:02:26
2021/04/09 10:03:26
2021/04/09 10:04:26
2021/04/09 10:05:26
2021/04/09 10:06:26
2021/04/09 10:07:26


2021/04/09 10:08:26
2021/04/09 10:09:26
2021/04/09 10:10:26
2021/04/09 10:11:26
2021/04/09 10:12:26

Basic performance cables (10 minutes, 1 photo every minute starting at t = 1 minute)


2021/04/09 10:56:46

2021/04/09 10:57:46

2021/04/09 10:58:46

2021/04/09 10:59:46

Basic performance cables in an office environment (8 minutes, 1 photo every minute starting at t = 1 minute)