BRANDWEER

Brandweeracademie

Impression tests chairs

De Brandweeracademie is onderdeel van het Instituut Fysieke Veiligheid.

Instituut Fysieke Veiligheid
Brandweeracademie
Postbus 7010
6801 HA Arnhem
www.ifv.nl
info@ifv.nl
026 355 24 00

Publication details

Fire Service Academy (2021). *Impression tests chairs*. Arnhem: Institute for Safety.

Commissioned by:	Professorship Fire Safety
Contact:	ing. R.R. Hagen MPA
Title:	Impression tests chairs
Date:	January 24, 2022
Status:	Final
Version:	1.0
Author:	ing. R.M.M. van Liempd, L. Wolfs BBA, ing. H.L. de Witte
Project leader:	ing. H.L. de Witte
Review:	ing. R.R. Hagen MPA
Final responsibility:	ing. R.R. Hagen MPA

Contents

Introduction

Background

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 36% of fires at home started in upholstered furniture and mattresses (Annual overview of fatal residential fires 2020, 2021). International research shows similar figures. The number of deaths and injuries can drop significantly if the fire safety of upholstered furniture and mattresses is improved.

In 2016 the Institute for Safety started a co-operation with a retailer with the purpose to initiate a new approach towards product requirements for upholstered furniture and mattresses. Those requirements should improve consumer safety significantly taking into account current living situations and current research on domestic fire safety. The overall goal is to improve domestic fire safety through safer home furnishing products. In order to achieve this on an industry wide scale the aim is to develop new product standards and to influence regulation in the EU.

The result of the co-operation is a public report with (recommended) test methods for upholstered furniture and mattresses. These test methods are supported by the FEU (the Federation of the European Union Fire Officers Associations) and selected based on knowledge, derived from both research and practical experience, of fire development, smoke spread, survivability and escape options in dwellings (Federation of the European Union Fire Officer Associations (FEU), 2017). The FEU report also refers to a study on impression tests with upholstered furniture and mattresses (Impression tests upholstered furniture and mattresses, 2017). In this study, the most frequently sold sofas and mattresses were tested for ignition and fire behaviour in a realistic residential environment.

The retailer has recently developed a chair in which another material composition is used than in conventional chairs. The next step in the partnership with the retailer is to perform impression tests with these new chairs and to compare their burning behaviour with that of conventional chairs.

Purpose and research questions

The retailer arranged the chairs for the impression tests to increase knowledge of technical solutions to material innovation and also fire safety. The purpose of this research is to get an impression of the burning behaviour of the newly developed chair and the probability of escape and survivability in the domestic area when exposed to different common test ignition sources (cigarette and crib 5). In addition, this research serves as a comparison between the new and the conventional chairs. As the purpose of the tests is to study the fire behaviour in a realistic environment, no laboratory tests have been carried out. Based on these objectives the following research questions have been defined.

Research question 1:
What is the burning behaviour in a single room environment of the new and conventional chair of the retailer when exposed to common test ignition sources such as a cigarette or crib 5?

Research question 2:
What is the probability of escape and survivability in a single room environment when only the new or conventional chair is burning?

Scope

As mentioned above, the purpose is to get an impression of the burning behaviour, probability of escape and survivability in a single room environment. In order to achieve this, a limited number of fire tests (experiments) have been carried out.
It should be noted however, that there is no such thing as a ‘standard single room environment’ or a ‘representative fire scenario’. For this reason, the tests have been carried out in a room that resembles a single room environment and a fire scenario that is common in practice. This means that this study is not intended to provide a comprehensive description of the burning behaviour and of the probability of escape and survivability in a residential environment.

1 Research method

This chapter describes the design of the experiments and of the analysis. As the purpose of this study is to get an impression of the burning behaviour of the chairs, only four experiments were carried out.

1.1 Experimental design

This section describes the experiments, containing a description of the test facilities and fire room, the objects, the ignition sources, measurements and measurement protocol and test protocol.

1.1.1 General description

The experiments took place on April 8, 2021. They were carried out on a fire training area (Troned Twente Safety Campus, the Netherlands). In this area a 20 feet ISO container was used as the fire room during the tests. The measurements of the ISO container are presented in table 1.1.

Table 1.1 The internal and outside measurements of the ISO container

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

The floorplan and an exterior view of the ISO container are presented in figure 1.1 and 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 burning behaviour, the new chairs and the conventional chairs were tested. The characteristics of the chairs are presented in table 1.2.

Table 1.2 Characteristics of the chairs

		New chair	Conventional chair
Chair frame	Leg	Solid birch, stain, clear acrylic lacquer	Solid beech, stain, clear acrylic lacquer
	Seat frame	Steel, epoxy/polyester powder coating	Solid wood, molded laminated wood veneer
	Backrest frame	Steel	Solid wood, molded laminated wood veneer
	Support panel	Polyethylene plastic	-
	Backrest cushion	100% polyester	Polyether 23 kg/m^3
	Seat cushion	100% polyester	Resilient HR foam 35 kg/m^3, polyester wadding
	Lining	Polyester wadding	Polypropylene fibre fabric
Chair cover	Fabric	100% cotton Back fabric: 100 % polyester (100% recycled)	65% polyester, 35% cotton

1.1.3 Ignition sources

There are well known test methods, standards, and ignition sources for testing upholstered furniture and mattresses. The prescribed ignition sources from the generally known test methods were used during the tests.

The following ignition sources were used:

> Test cigarettes (SRM 1196)

> Larger ignition source (crib 5).

Both chairs are developed to pass a cigarette test according to EN 1021-1.

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 (NO_x) were measured. The measurements were started when the object was exposed to the ignition source.
The temperature was measured at two positions in the fire room and on three levels (0.5, 0.9, 1.5, 1.8 and 2.2 meters). The gas measurements (CO, CO_2, NO_x, and O_2) were measured at two positions and on two levels (0.5 and 1.5 meters). Radiation heat flux was measured at two positions, also on two levels (0.5 and 1.5 meters). On each level one sensor was directed to the fire source and another sensor 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 the other 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 burning behaviour and the release of smoke. One camera was placed on the floor in the doorway and the other was placed outside. Both cameras faced the fire source.

The test object was placed on a scale to measure the mass loss during the experiment. This scale has four measuring points. On top of those points a steel frame, a wooden panel and plasterboard were placed. The test object was placed on top of the plasterboard.

The specifications of the measurements, devices and position can be found in table 1.3 and figure 1.3.

Table 1.3 Specifications of the measurements

Parameter	Measurement device	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 sensor	5x per second	1 position	2 levels: 0.5 and 1.5m On each level 1 faces fire source and 1 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
Mass loss	Scale	5x per second	1 position	Average of 4 points

The measurement tools for the gases were placed through holes in the side wall of the container, as shown in figure 1.3 and figure 1.4. In this way the measurement tools could be protected against heat and safely be retrieved if necessary. However, this means that the measurements have taken place approximately 30 cm from the side wall of the fire room, while it is logical to take measurements in the middle of the room. This choice was made in favour of the safety of the measurement tools.

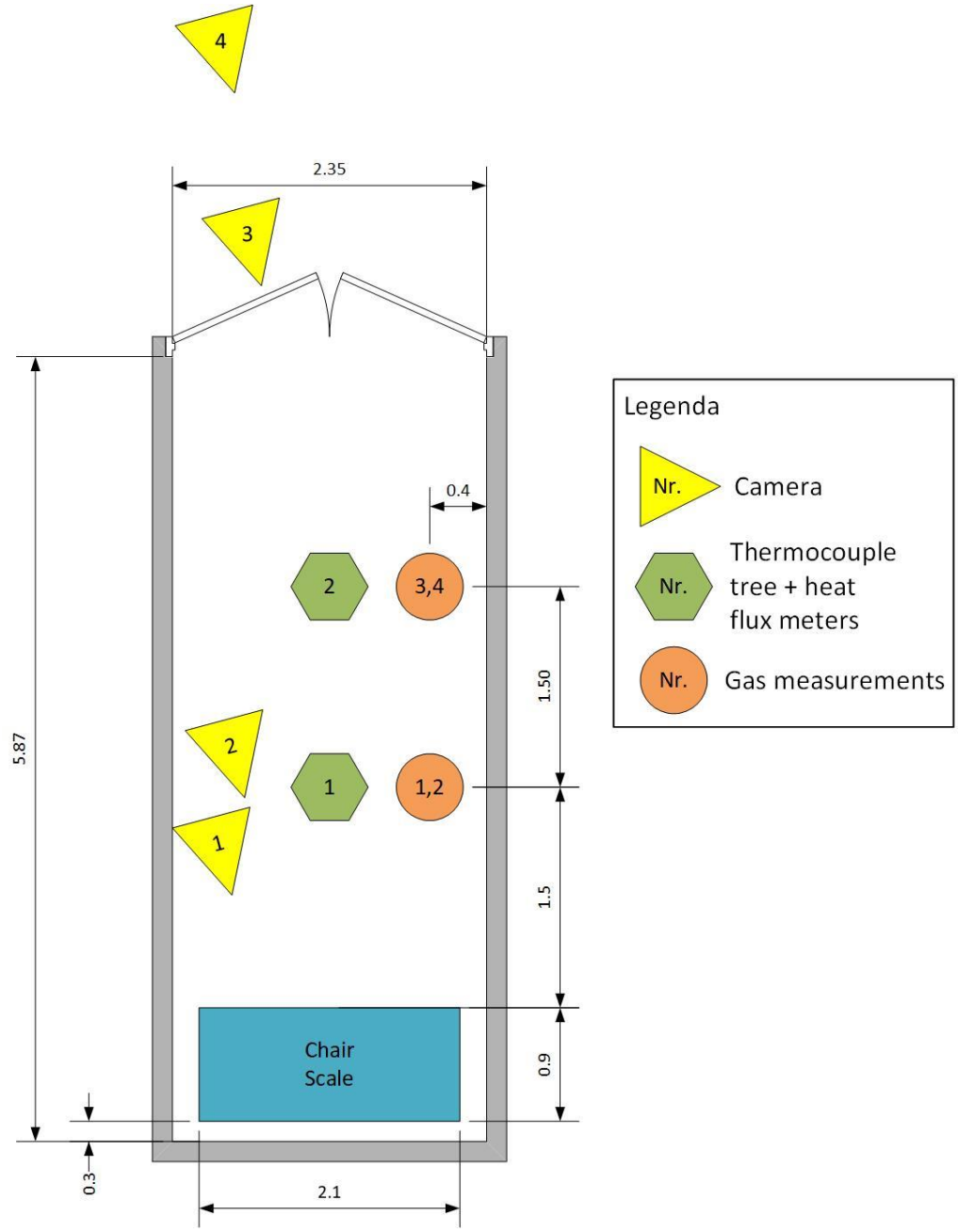


Figure 1.3 Floor plan with measurement devices

Figure 1.4 Test set-up

1.1.5 Test protocol

The protocols that were used are described below.

Cigarette test

The test with cigarettes as an ignition source was only intended to test whether a cigarette as an ignition source can cause a (smouldering) fire. These tests were not carried out in the fire room but in the open air.

The test protocol of the cigarette tests was as follows:

> Ignite cigarette and supply air to the cigarette until a minimum of 5 and a maximum of 8 mm of the cigarette have been incinerated.
> Place the cigarette on the chair (2 locations for every chair, one in the middle of the seat, one in the corner between the seat and the backrest).
> Wait for flames to develop or a progressive soldering fire.
> If this does not happen within an hour, this is considered as ‘chair not ignited’.
> If the cigarette burns down or dies out and no smouldering fire is visible on the chair, this is also considered as ‘chair not ignited’.
> If flames develop, extinguish them with a small amount of water.

Crib 5 test

The fire tests with crib 5 as an ignition source were carried out in the fire room. The crib 5 was placed on the seat of the chair in the corner with the backrest and the crib was ignited. When no flames were visible after the crib 5 had burned away, the test was aborted. If flames were visible after burning the crib 5, the test was terminated after 20 minutes or when the object was (largely) burned.

Both chairs were tested twice, once with the door of the fire room open and once with the door of the fire room closed. In the tests with the door closed, one door to the fire room was left completely open for the first minute of the test in order to observe the progress. After one minute, this door was closed against the closing hook of the container door with a block of concrete (see figure 1.5). In that way there was a small gap, which can be considered as comparable to the leakage area that every room has.

Figure 1.5 Fire room with the door in closed position

Summary of the fire tests

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

Table 1.4 Fire tests

Object	Door position	Ignition source	Test no.
New chair 1	> - > Door closed	> Cigarette > Crib 5	> - > 1
New chair 2	> - > Door open	> Cigarette > Crib 5	> - > 2
Conventional chair 1	> - > Door closed	> Cigarette > Crib 5	> - > 3
Conventional chair 2	> - > Door open	> Cigarette > Crib 5	> - > 4

1.2 Data analysis

1.2.1 Limit values for ignition

Following the experiments, the visible data were analysed using the limit values for ignition. These values are practical limits that are not the same as limit values used for commonly

known test methods. However, these limits give an impression about the ignitability of the objects. The following limit values were used:

> Cigarette test: no flames visible from the start of the test until 1 hour after the cigarette has completely burned down or no (smouldering) fire visible after the cigarette has completely burned down.
> Crib 5 test: no flames visible after burning the crib.

1.2.2 Threshold values for the possibility of escape and survivability

Following 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 of data analysis and determination of the possibility of escape and survival 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 the available safe escape time (ASET) needs to be longer than the required safe escape time (RSET), the possibility of escape and survival for people who are present until the moment they escape or are rescued is determinative in preventing fire casualties. The conditions to which people are exposed and their vulnerability for those conditions are decisive for the available safe escape and survival time.

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

> irritant and asphyxiant gases
> heat
> visibility.

These fire conditions can lead to the possibility of escape being impaired, to a life-threatening situation, or even to a fatal situation (see figure 1.6).

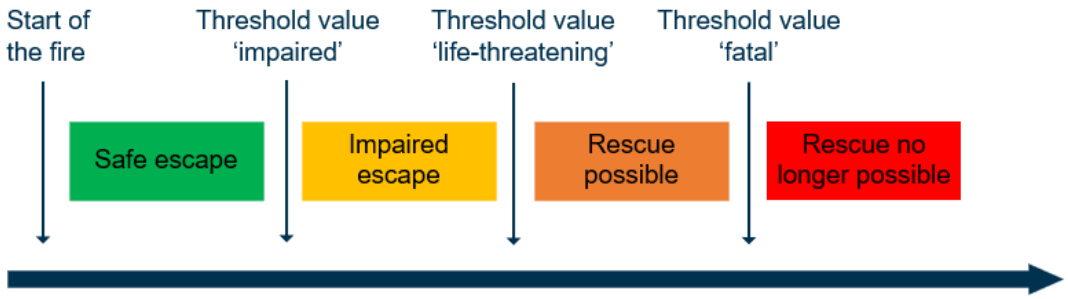


Figure 1.6 Diagram of the possibility of escape and survivability in the event of fire

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 (Fire Service Academy, 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 are being 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 according to the *SFPE Handbook* can be found in table 1.5.

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

Fire condition	Method	Impaired			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	FEC_{smoke}	0.1	0.3	1.0	-	-	-	-	-	-

2 Results

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

> Results of the cigarette tests: section 2.1
> Results of the crib no. 5 tests: section 2.2 for the new chair and section 2.3 for the conventional chair
> Comparison of the new and conventional chair: section 2.4.

In addition, an analysis of the results is given, presented as follows:

> Cigarette tests
  – Photos of the tests
> Results of the crib no. 5 tests
  – Images of the test
  – A temperature graph
  – A carbon monoxide concentration graph
  – An oxygen concentration graph
  – A 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 new and conventional chair
  – Images of the fire tests with the door open
  – Stacked bars 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.

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

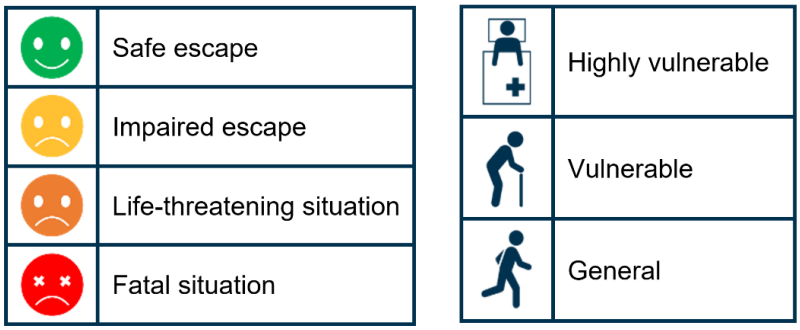


Figure 2.1 Symbols for four situations (left) and icons of three groups (right)

The discussion of the results and the analysis in this chapter are a summary of all results and an 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, FECsmoke) for each measurement location and test.
> Appendix 3: images of the tests.

2.1 Cigarette tests

In this section the results from the cigarette test are shown.

2.1.1 Cigarette test new chairs

Figure 2.2 and figure 2.3 show images of the cigarette tests with the new chairs. The cigarette in the corner of the seat and the backrest in figure 2.2 stopped burning before it had completely burned away. Another cigarette that was put in the same position also stopped burning. This was noted as no ignition for this position.

Figure 2.2 Cigarette test new chair in the corner of the seat and backrest

Figure 2.3 Cigarette test new chair in the middle of the seat

Analysis

The photos show that the chair is not ignited by a burning cigarette. After the cigarette is extinguished, no smouldering appears in the filling or in the cover of the chair. Only the top layer is slightly melted away. The new chair passed the cigarette test, which was expected because the chair is developed to pass the test according to EN 1021-1

2.1.2 Cigarette test conventional chairs

Figure 2.4 and figure 2.5 show images of the cigarette test with the conventional chairs.

Figure 2.4 Cigarette test conventional chair in the corner of the seat and backrest

Figure 2.5 Cigarette test conventional chair in the middle of the seat

Analysis
The photos show that the chair is not ignited by a burning cigarette. After the cigarette is extinguished, no smouldering appears in the filling or in the cover of the chair. Only the top layer is slightly melted. The conventional chair passed the cigarette test, which was expected because the chair is developed to pass the test according to EN 1021-1.

2.2 Crib 5 tests new chairs

In this section the results of the crib 5 tests with the new chair are presented.

2.2.1 Crib 5 new chair door closed (test 1)

Below the results for test 1 are presented with:

> Images of the test (figure 2.6 till figure 2.11)
> Graphs of measured values during the test (figure 2.12 till figure 2.14)
> A table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (table 2.1)

Figure 2.6 Start crib 5 test

Figure 2.7 Two minutes after start test

Figure 2.8 Four minutes after start test

Figure 2.9 Six minutes after start test

Figure 2.10 Ten minutes after start test

Figure 2.11 Chair after the test

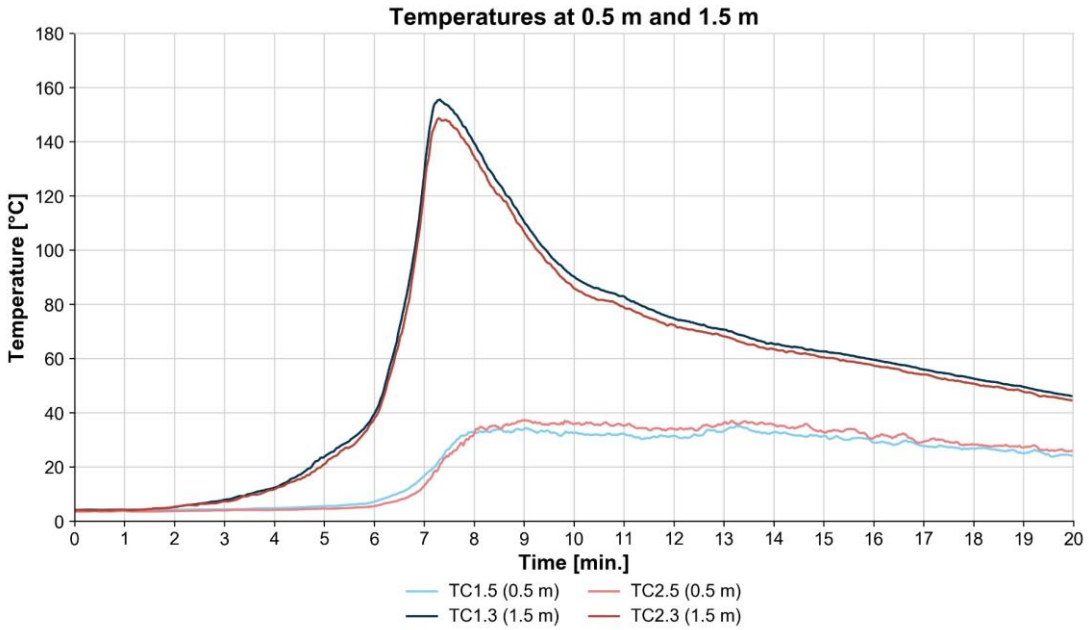


Figure 2.12 Temperatures at 0.5 and 1.5 m height [°C] for test 1

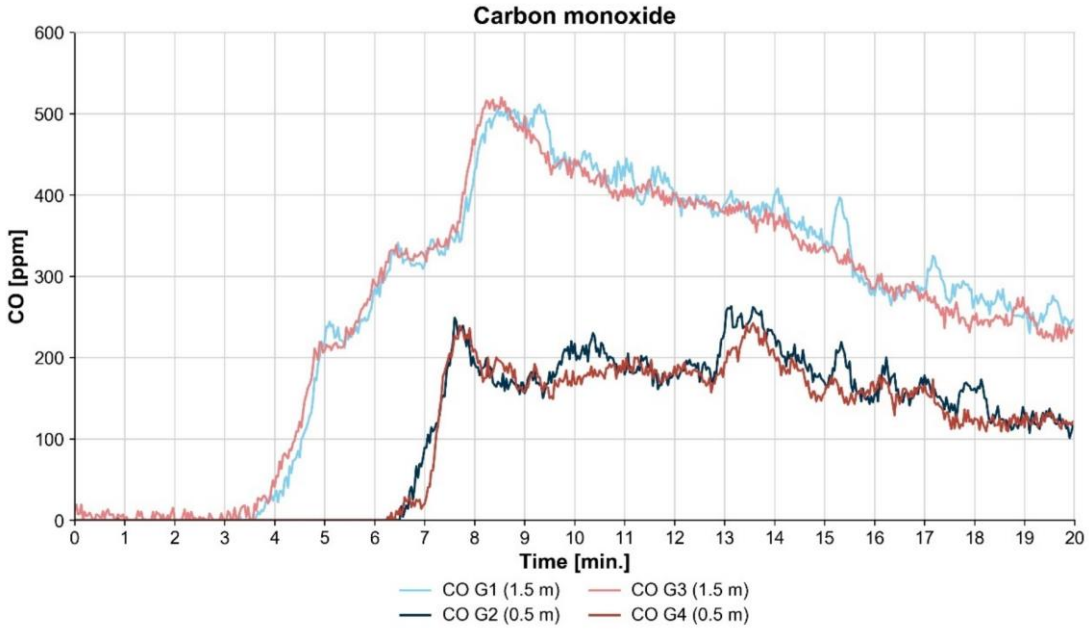


Figure 2.13 Carbon monoxide concentration at 4 locations [ppm] for test 1

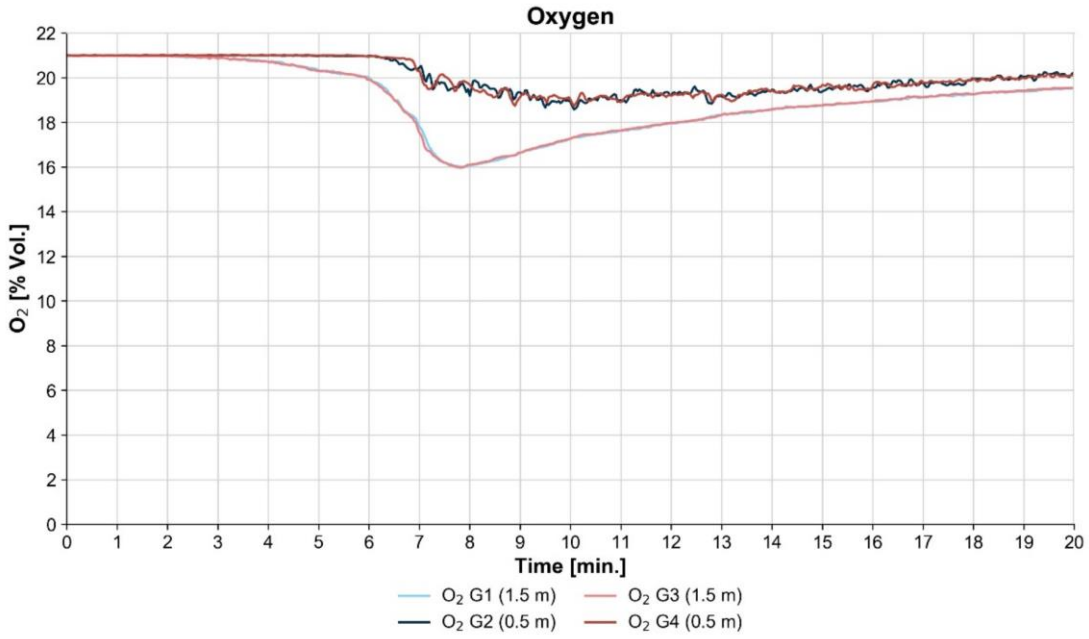


Figure 2.14 Oxygen concentration at 4 locations [% vol.] for test 1

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	< 7	7	8	10	< 7	7	13	N.R.	< 11	11	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
During the test, the maximum temperature was about 240 °C after 7 minutes (at a height of 2.2 m). The maximum carbon monoxide concentration measured was about 500 ppm after 8 minutes. The chair was almost completely burned after the test. For the general group this results in a survivable situation for the complete duration of the test. At a height of 1,5 meter there is an impaired escape after 11 minutes for the general group. The vulnerable group has an impaired escape after 7 minutes and a life-threatening situation is reached after 13 minutes at a height of 1,5 meter. The limit value for a fatal situation is not reached for the vulnerable group. The highly vulnerable group has an impaired escape after 7 minutes, a life-threatening situation after 8 minutes and a fatal situation after 10 minutes at a height of 1,5 meter. At a height of 0,5 meter there is a possibility of safe escape for the complete duration of the test.

The irritant gases and heat cause an impaired escape at about the same time for the highly vulnerable group. For the vulnerable and general group, only heat causes an impaired escape. Visibility was not measured but based on video footage it can be concluded that the visibility will probably cause an impaired escape at a height of 1,5 meter within 6 minutes. Visibility would probably be the first fire condition to reach the limit value for an impaired escape.

The asphyxiant gases are the first to cause a life-threatening or fatal situation for the (highly) vulnerable group. Heat also reaches the limit value for a life-threatening or fatal situation for the highly vulnerable group. For the vulnerable group heat does not reach the limit value for a life-threatening situation. For the general group, the limit value for a life-threatening or fatal situation is not reached.

All the fire conditions (visibility, heat, irritant and asphyxiant gases) play a role in the possibility of escape and survivability. In some cases, the limit value is reached for more than one condition.

The lowest oxygen concentration was about 16 vol. %. This might have had some influence on the speed and intensity of the burning of the chair.

Based on the heat flux, a fire might propagate to objects nearby the fire. At the location of the measured heat flux gauges (1.65 meter from the side of the chair) the heat flux was too low to ignite other objects.

2.2.2 Crib 5 new chair door open (test 2)
Below the results for test 2 are presented with:
> Images of the test (figure 2.15 till figure 2.20)
> Graphs of measured values during the test (figure 2.21 till figure 2.23)
> A table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (table 2.2).

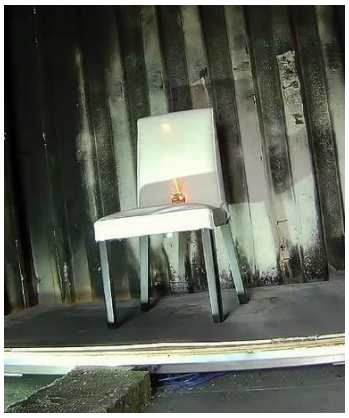


Figure 2.15 Start crib 5 test

Figure 2.16 Two minutes after start test

Figure 2.17 Four minutes after start test

Figure 2.18 Six minutes after start test

Figure 2.19 Ten minutes after start test

Figure 2.20 Chair after the test

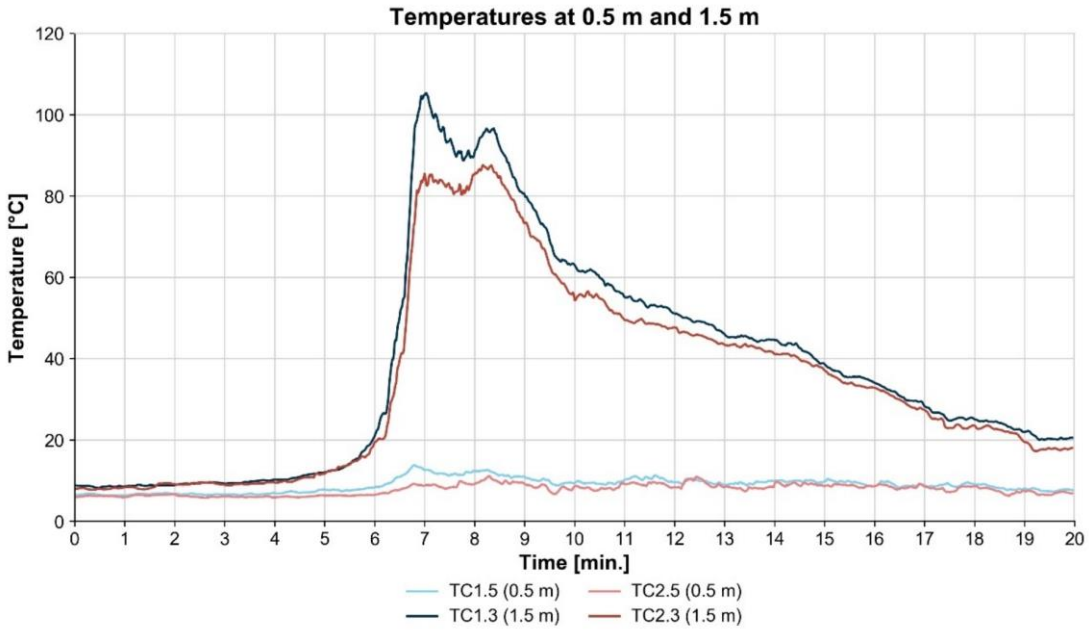


Figure 2.21 Temperatures at 0.5 and 1.5 m height [°C] for test 2

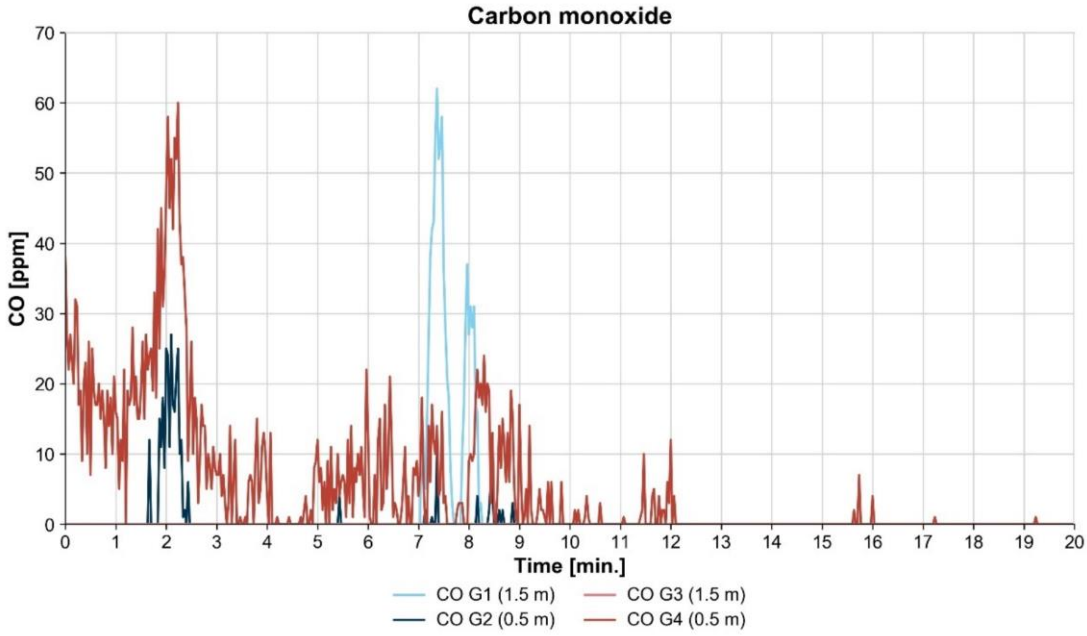


Figure 2.22 Carbon monoxide concentration at 4 locations [ppm] for test 2

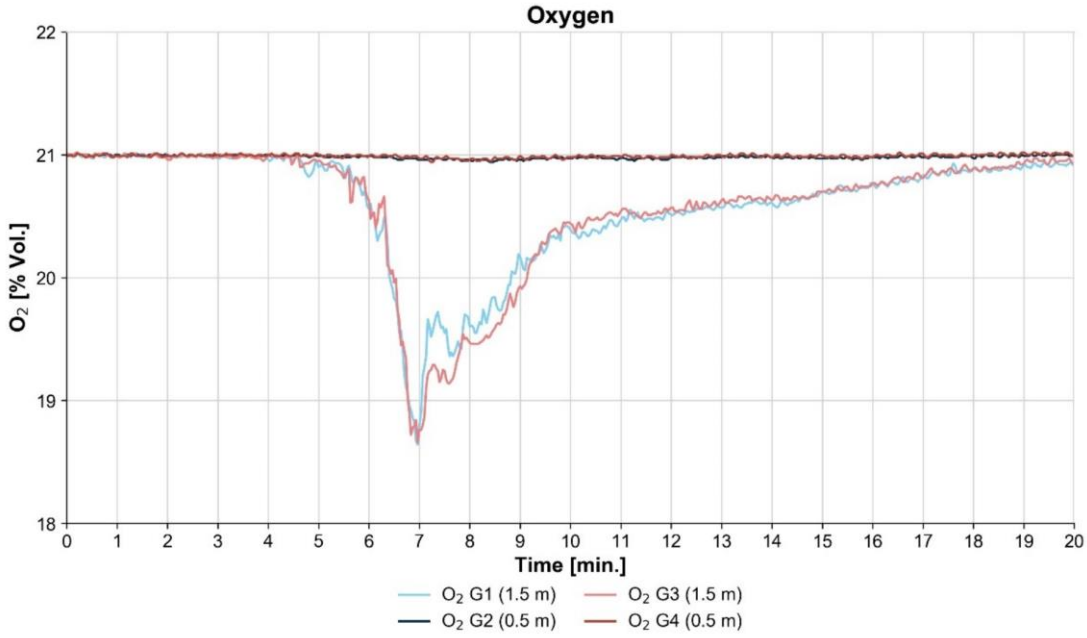


Figure 2.23 Oxygen concentration at 4 locations [% vol.] for test 2

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	< 7	7	N.R.	N.R.	< 11	11	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
During the test, the maximum temperature was circa 220 °C after 7 minutes (at a height of 2.2 m). The maximum carbon monoxide concentration measured was about 60 ppm after 2 minutes. Because the door of the fire room was open, a lot of fresh air entered the fire room and smoke went outside of the room. 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 went to the outside of the container. The peak carbon monoxide concentration would probably have been higher at a greater height. The chair was almost completely burned after the test. This resulted in a survivable situation for the complete duration of the test for all three groups. At a height of 1,5 meter there was an impaired escape after 7 minutes for the highly vulnerable group and after 11 minutes for the vulnerable group. At the same height there is a possibility of safe escape for the complete duration of the test for the general group. At a height of 0,5 meter this was possible for all three groups.

Heat was the only fire condition that caused an impaired escape for the (highly) vulnerable group at a height of 1,5 meter. Visibility was not measured but based on video footage the visibility would probably cause an impaired escape at a height of 1,5 meter within 7 minutes. Therefore, visibility would probably be the first fire condition to reach the limit value for an impaired escape, especially for the vulnerable and general group.

The fire conditions visibility and heat play a role in the possibility of escape. Because a lot of smoke gases left the fire room, the irritant and asphyxiant gases did not influence the possibility of escape and the survivability.

Caused by the heat flux, a fire might propagate to objects nearby. At the location of the measured heat flux gauges (1.65 meter from the side of the chair) the heat flux during the tests was too low to ignite other objects.

2.3 Crib 5 tests conventional chairs

In this section the results of the crib 5 tests with the conventional chair are presented.

2.3.1 Crib 5 conventional chair door closed (test 3)

Below the results for test 3 are presented with:
> Images of the test (figure 2.24 till figure 2.29)
> Graphs of measured values during the test (figure 2.30 till figure 2.32)
> A table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (table 2.3).

Figure 2.24 Start crib 5 test

Figure 2.25 Two minutes after start test

Figure 2.26 Four minutes after start test

Figure 2.27 Six minutes after start test

Figure 2.28 Ten minutes after start test

Figure 2.29 Chair after the test

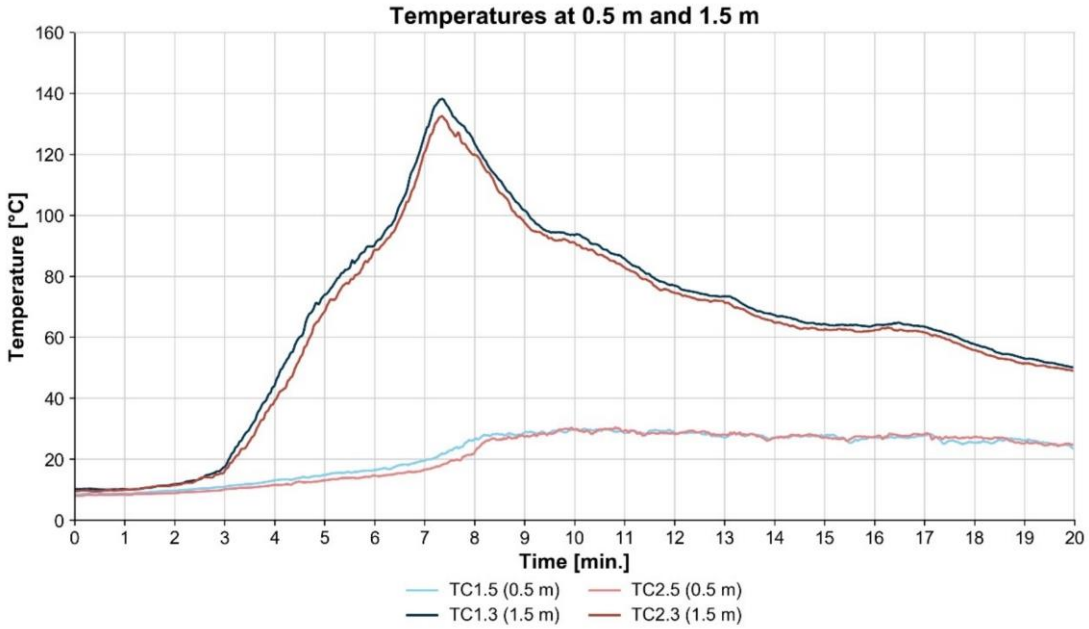


Figure 2.30 Temperatures at 0.5 and 1.5 m height [°C] for test 3

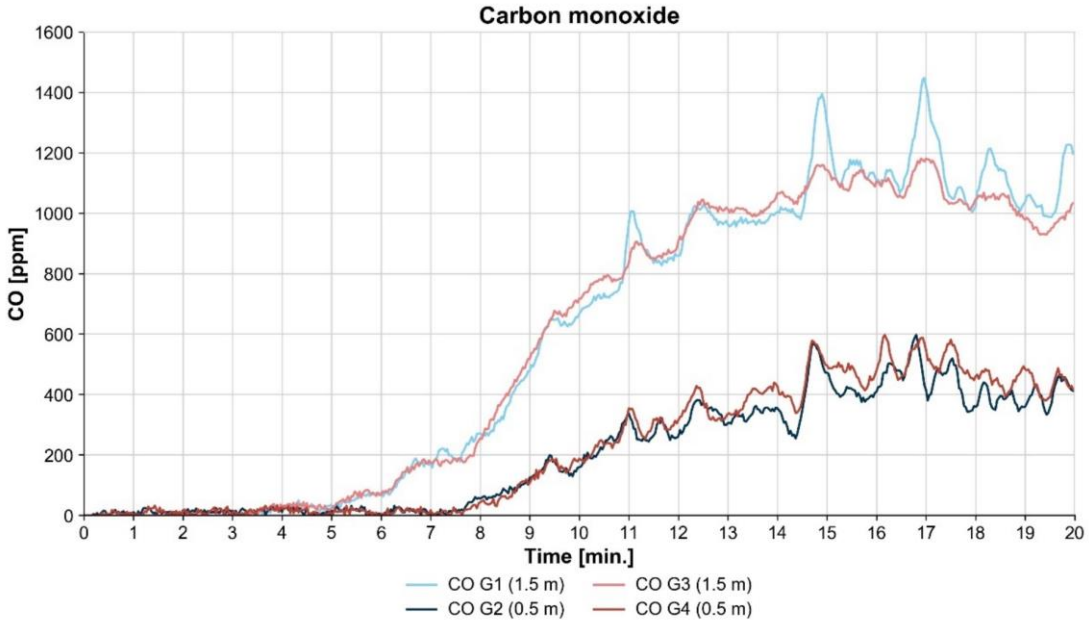


Figure 2.31 Carbon monoxide concentration at 4 locations [ppm] for test 3

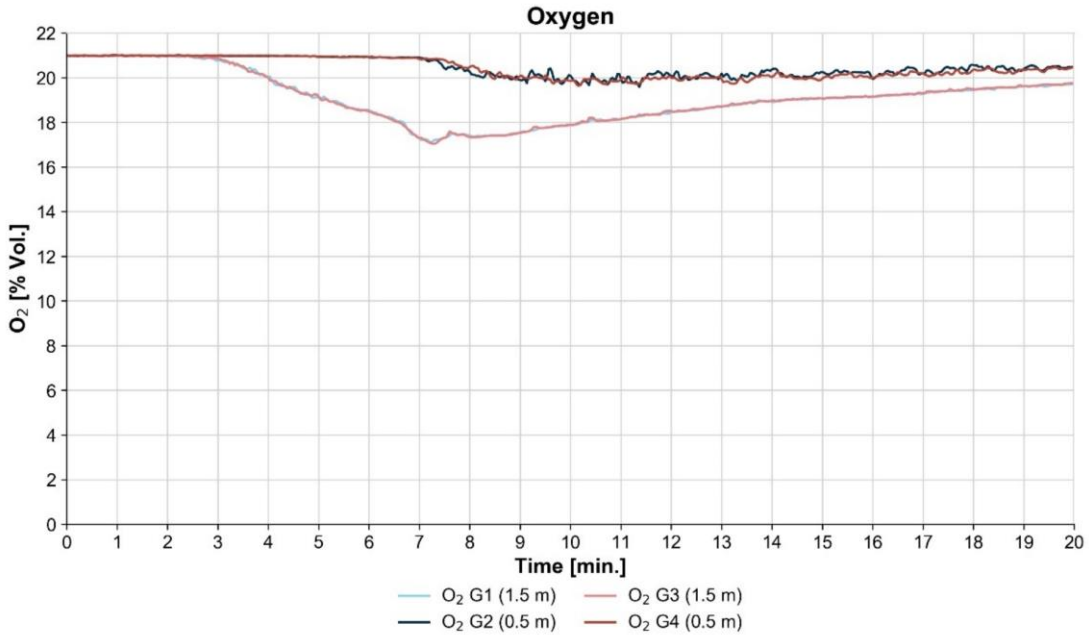


Figure 2.32 Oxygen concentration at 4 locations [% vol.] for test 3

Table 2.3 Times for the possibility of escape and survivability (in minutes) for test 3

Height												
0.5 m	< 8	8	10	13	< 15	15	15	N.R.	> 20	N.R.	N.R.	N.R.
1.5 m	< 3	3	5	6	< 4	4	7	9	< 11	11	11	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

During the test, the maximum temperature was circa 190 °C after 7 minutes (at a height of 2.2 m). The maximum carbon monoxide concentration measured was about 1450 ppm after 17 minutes. The chair was almost completely burned after the test. For the highly vulnerable group this resulted in a life-threatening situation after 5 minutes (height 1,5 meter) and 10 minutes (height 0,5 meter) and a fatal situation after 6 minutes (height 1,5 meter) and 13 minutes (height 0,5 meter). For the vulnerable group, a life-threatening situation occurred after 7 minutes and a fatal situation occurred after 9 minutes at a height of 1,5 meter. At a height of 0,5 meter a life-threatening situation occurred after 15 minutes; however, a fatal situation did not occur during the complete duration of the test for the vulnerable group. For the general group, a life-threatening situation occurred after 11 minutes at a height of 1,5 meter. A fatal situation did not occur for the general group during the complete duration of the test. At a height of 0,5 meter, it was possible for the general group to safely escape for the complete duration of the test.

The irritant gases were the first to cause an impaired escape for the (highly) vulnerable group. Within a few minutes after the irritant gases would cause an impaired escape, heat would have the same effect for the (highly) vulnerable group at a height of 1,5 meter. For the general group heat was the only fire condition that caused an impaired escape at a height of 1,5 meter. Visibility was not measured but based on video footage the visibility would probably cause an impaired escape at a height of 1,5 meter within 4 minutes. Visibility would probably be the first fire condition to reach the limit value for an impaired escape for the general group. For the (highly) vulnerable group visibility would probably cause an impaired escape at about the same time as the irritant gases.

The asphyxiant gases were the only fire condition that caused a life-threatening situation for the vulnerable and general group. Heat and irritant gases also reached the limit value for a life-threatening situation for the highly vulnerable group at a height of 1,5 meter. The irritant and asphyxiant gases reached the limit value for a life-threatening situation at about the same time for the highly vulnerable group. Heat did not reach the limit value for a life-threatening situation at a height of 0.5 meter for all three groups.

The asphyxiant gases were the first to reach the limit value for a fatal situation for the (highly) vulnerable group. For the vulnerable group, the asphyxiant gases were the only fire condition that reached the limit value for a fatal situation. For the highly vulnerable group at a height of 1.5-meter heat would cause a fatal situation after the asphyxiant gases had already done so. Heat did not reach the limit value for a fatal situation at a height of 0.5 meter for all three groups. For the general group, a fatal situation did not occur during the complete duration of the test.

All the fire conditions (visibility, heat, irritant and asphyxiant gases) played a role in the possibility of escape and the survivability. In some cases, the limit value was reached for more than one fire condition.

The lowest oxygen concentration was about 17 vol. %. This might have some influence in the speed and intensity of the burning of the chair. Based on the heat flux, fire might propagate to objects nearby the fire. At the location of the measured heat flux gauges (1.65 meter from the side of the chair) the heat flux was too low to ignite other objects.

2.3.2 Crib 5 conventional chair door open (test 4)

Below the results for test 4 are presented with:

> Images of the test (see figure 2.33 till figure 2.38)
> Graphs of measured values during the test (see figure 2.39 till figure 2.41)
> A table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (table 2.4).

Figure 2.33 Start crib 5 test

Figure 2.34 Two minutes after start test

Figure 2.35 Four minutes after start test

Figure 2.36 Six minutes after start test

Figure 2.37 Ten minutes after start test

Figure 2.38 Chair after the test

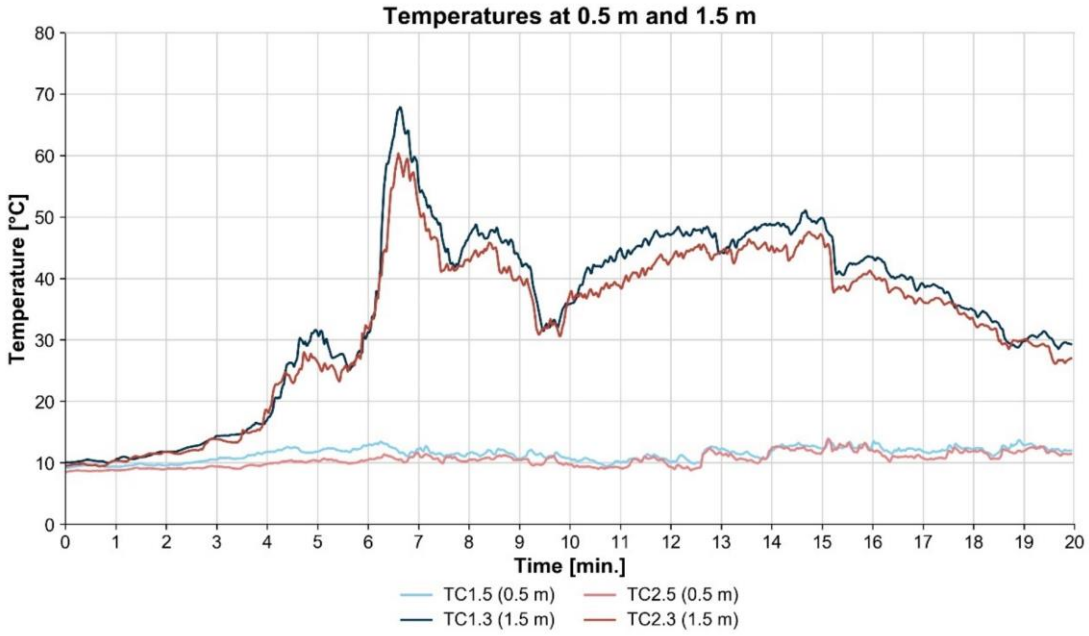


Figure 2.39 Temperatures at 0.5 and 1.5 m height [°C] for test 4

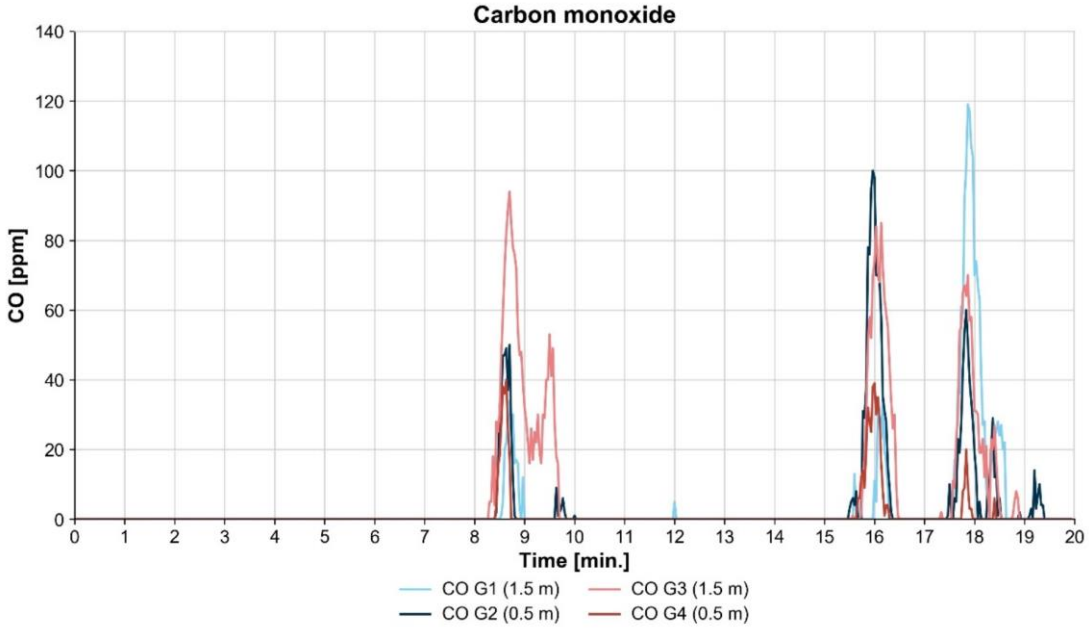


Figure 2.40 Carbon monoxide concentration at 4 locations [ppm] for test 4

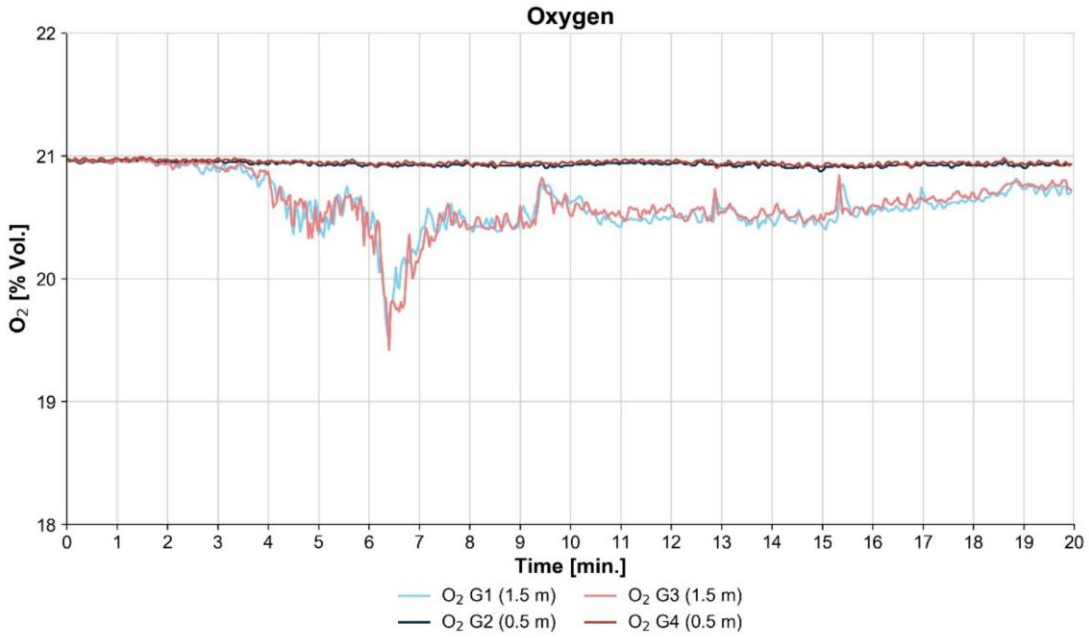


Figure 2.41 Oxygen concentration at 4 locations [% vol.] for test 4

Table 2.4 Times for the possibility of escape and survivability (in minutes) for test 4

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	< 5	5	11	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

During the test, the maximum temperature was about 160 °C after 6 minutes (at a height of 2.2 m). The maximum carbon monoxide concentration measured was about 120 ppm after 18 minutes. Because the door of the fire room was open, a lot of fresh air came inside the fire room and smoke went outside of the room. 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 have probably been higher at a higher height. The chair was almost completely burned after the test. This results in a possibility for a safe escape for the complete duration of the test for the general and vulnerable group. For the highly vulnerable group an impaired escape occurred after 5 minutes and a life-threatening situation after 11 minutes at a height of 1,5 meter. A fatal situation did not occur for the highly vulnerable group during the complete duration of the test. At a height of 0,5 m there is a possibility of a safe escape for the complete duration of the test for the highly vulnerable group.

Irritant gases were the first fire condition to cause an impaired escape for the highly vulnerable group at a height of 1,5 meter. Heat also caused an impaired escape for the highly vulnerable group at the same height. Visibility was not measured but based on video footage the visibility would probably cause an impaired escape at a height of 1,5 meter within 6 minutes. Visibility would probably be the first fire condition to reach the limit value for an impaired escape, especially for the vulnerable and general group.

The asphyxiant gases were the only fire condition that caused a life-threatening situation for the highly vulnerable group at a height of 1,5 meter.

All the fire conditions (visibility, heat, irritant and asphyxiant gases) played a role in the possibility of escape and the survivability. In some cases, the limit value was reached for more than one fire condition.

Based on the heat flux, fire might propagate to objects nearby the fire. At the location of the measured heat flux gauges (1.65 meter from the side of the chair) the heat flux was too low to ignite other objects.

2.4 Comparison of the new and conventional chair

In this section the burning behaviour of the new and conventional chair and the possibility to escape and survivability in relation to both chairs are compared. The results are presented using images from the tests with the door open (see figure 2.42 till figure 2.51) and with stacked bars 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 (see figure 2.52 and figure 2.53). At the end of this section the differences in burning behaviour and the possibility to escape and survivability are analysed.

Images of the fire tests with the door open

Figure 2.42 Fire new chair after 2 minutes

Figure 2.43 Fire conventional chair after 2 minutes

Figure 2.44 Fire new chair after 3 minutes

Figure 2.45 Fire conventional chair after 3 minutes

Figure 2.46 Fire new chair after 6 minutes

Figure 2.47 Fire conventional chair after 6 minutes

Figure 2.48 Fire new chair after 8 minutes

Figure 2.49 Fire conventional chair after 8 minutes

Figure 2.50 Fire new chair after 12 minutes

Figure 2.51 Fire conventional chair after 12 minutes

Times for the possibility of escape and survivability in tests with the door closed

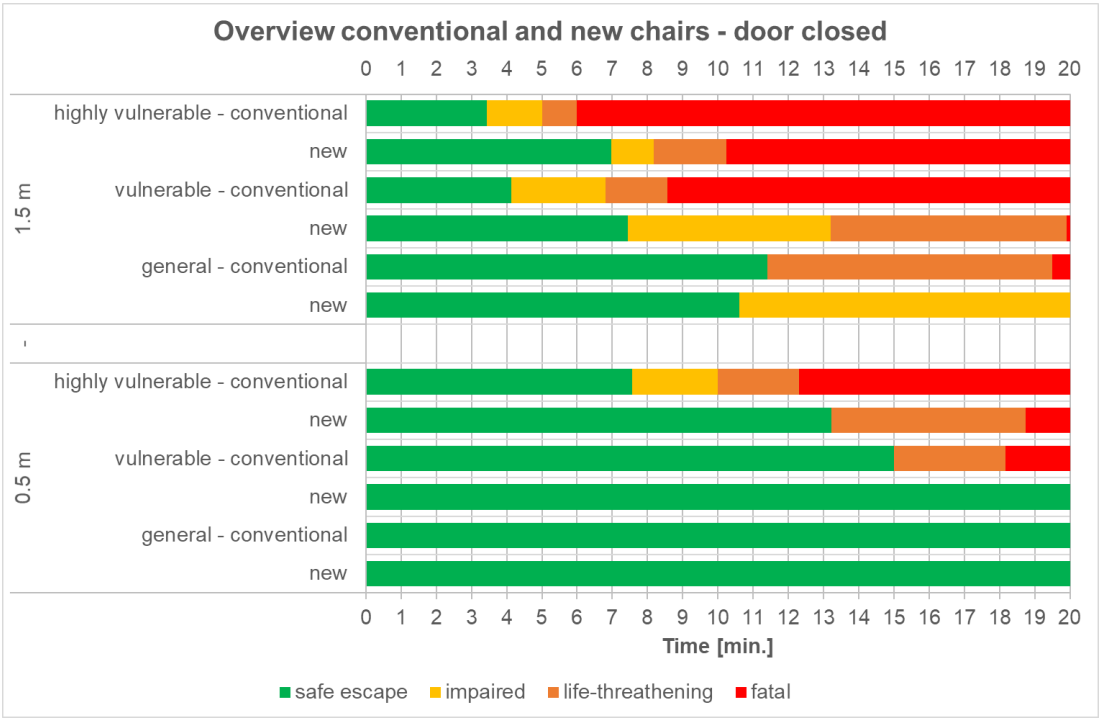


Figure 2.52 Times for the possibility of escape and survivability of the tests with the door closed

Times for the possibility of escape and survivability in tests with the door open

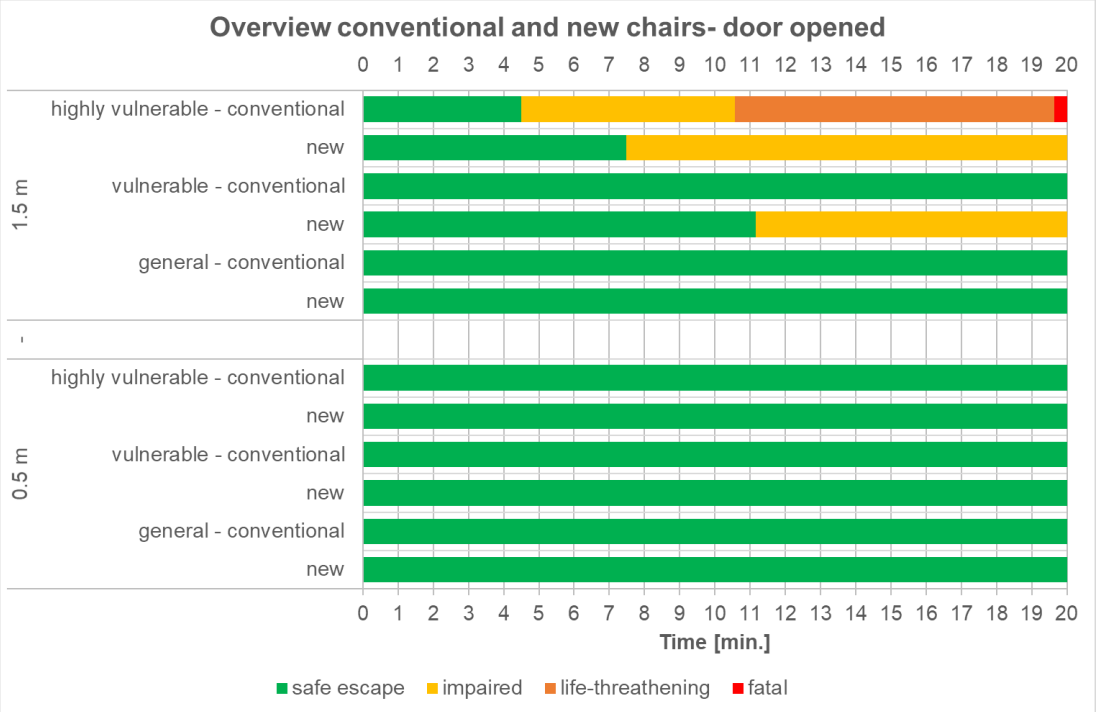


Figure 2.53 Times for the possibility of escape and survivability of the tests with the door open

Analysis

Based on the video footage of the test with the door open, the fire progressed in the new and conventional chair in a different pace. In the first three minutes the fire progressed faster in the conventional chair. After 3 minutes almost the entire backrest of the conventional chair was burning. Of the new chair only one third of the backrest was involved in the fire at that time. As a larger part of the conventional chair was involved in the fire, the intensity of the fire (based on flame volume) of the conventional chair was higher; in addition, more soot was produced compared to the new chair. After 6 minutes the intensity of the fire was more or less the same for both chairs. However, after 6 minutes the intensity of the fire in the new chair still increased, while it decreased in the conventional chair. At the same time burning droplets fell from the new chair on the floor, causing a secondary fire. Of the conventional chair, only a few burning droplets fell down. After 8 minutes the intensity of the fire in the new chair started to decrease slowly, and after 12 minutes the intensity of the fire in both chairs was about the same again. At that time, the biggest part of both chairs was burned away.

The intensity of the fire can also be seen in the temperature graphs. The new chair reached a higher peak temperature at a later moment in time (220 °C at 7 minutes versus 160 °C at 6 minutes) in the test with the door open. The difference in gas concentrations can best be seen in the test with the door closed. In the test with the door open most smoke gases left the container at a higher point than the measuring height of 1,5 meter. The difference in the intensity of the fire of the new and conventional chairs is not reflected in all the measured gas concentrations in the tests with the door closed. The peak CO_2 concentration is more or less the same for both types of chairs (2,2 vol. % for the new chair and 2,8 vol. % for the

conventional chair). The minimum oxygen concentration is also similar (16 vol. % for the new chair and 17 vol. % for the conventional chair). There is however quite a big difference in the nitrogen oxides and carbon monoxide concentrations. The conventional chair has a peak nitrogen oxides concentration of almost 160 ppm after 7 minutes while the new chair has a peak concentration of 18 ppm after 7 minutes. The peak carbon monoxide concentration is about 500 ppm after 8 minutes for the new chair. After 8 minutes the carbon monoxide drops to a maximum of about 250 ppm at the end of the test. For the conventional chair, the maximum carbon monoxide concentration at 8 minutes is 250 ppm, half of the carbon monoxide concentration of the new chair. The carbon monoxide concentration keeps on rising after 8 minutes for the conventional chair and reaches a peak concentration of about 1450 ppm after 17 minutes. The conventional chair seems to produce substantially more nitrogen oxides and carbon monoxide than the new chair. However, at the time when the fire intensity is almost the same (6 minutes), the conventional chair produces less carbon monoxide than the new chair (100 versus 300 ppm). This could be related to the parts of the chair that are burning at various moments during the test.

Overall, the new chair has longer times for the possibility of escape and survivability in the test with the door closed. For the highly vulnerable group with a burning new chair a life-threatening and fatal situation is reached 3 to 4 minutes later, compared to the conventional chair (5 versus 8 minutes and 6 versus 10 minutes). Although less irritant and asphyxiant gases are produced by the fire in the new chair, the gas concentrations are still high enough to cause a life-threatening situation for the highly vulnerable group. As the new chair produces less irritant and asphyxiant gases, a fatal situation does not occur for the vulnerable group (9 minutes with the conventional chair). For the general group, a life-threatening situation does not occur at all with a burning new chair, while with a burning conventional chair a life-threatening situation is reached after 11 minutes. Just one burning conventional chair inside a room of about 14 m^2 is enough to cause a fatal situation for the (highly) vulnerable group and a life-threatening situation for the general group. Similarly, only one burning new chair can cause a fatal situation for the highly vulnerable group and a life-threatening situation for the vulnerable group. However, for the general group a burning new chair does not cause a life-threatening situation.

3 Findings

3.1 Research question 1

What is the burning behaviour in a single room environment of the new and conventional chair of the retailer when exposed to common test ignition sources such as a cigarette or crib 5?

Both the conventional and the new chair did not ignite in the cigarette test. This is expected because both chairs were developed to pass a cigarette test according to EN 1021-1. However, both chairs did catch fire with a crib 5 as an ignitor.

On the conventional chair, the fire spreads fairly fast over the backrest: almost the entire backrest was involved in the fire after 3 minutes. The peak intensity of the fire was reached around 6 minutes. The highest gas concentrations measured for the conventional chair were around 1450 ppm for carbon monoxide (CO) after 17 minutes and 160 ppm for nitrogen oxides (NO_x) after 7 minutes.

Regarding the new chair, the peak intensity of the fire was reached around 8 minutes. The highest gas concentrations measured were around 500 ppm for carbon monoxide (CO) after 8 minutes and 18 ppm for nitrogen oxides (NO_x) after 7 minutes.

With respect to both chairs, the fire might propagate to other objects nearby. However, at the location of the measured heat flux gauges (1.65 meter from the side of the chair), the heat flux was not high enough to ignite other objects.

3.2 Research question 2

What is the probability of escape and survivability in a single room environment when only the upholstered new or conventional chair is burning?

Just one burning conventional chair inside a room of about 14 m^2 with the door closed is in itself enough to cause a fatal situation after 6 to 9 minutes for the (highly) vulnerable group and a life-threatening situation after 12 minutes for the general group.

Similarly, only one burning new chair can cause a fatal situation after 10 minutes for the highly vulnerable group and a life-threatening situation after 13 minutes for the vulnerable group. For the general group a burning new chair does not cause a life-threatening situation. Both the conventional and the new chair did not cause a life-threatening situation when the door of the fire room was open.

4 Discussion

In this chapter some limitations of this study regarding the scope of the findings and the research method are discussed.

The results of this study are obviously only valid for the configurations studied and can therefore strictly speaking not be generalized, except with common sense and the necessary caution.

As limitations can be mentioned:

> Only four objects (two new and two conventional chairs) were used in the experiments. It is unclear if these objects are representative for upholstered furniture in general. Something similar can be said about the results of each test, as the tests per object were not repeated.
> The fire room has the dimensions of a small living room or a bedroom (14 m2). Different room dimensions could lead to different results. The material of the enclosure (steel container) influences the parameter heat. Accordingly, other materials such as brick could lead to different results. Additionally, the door of the container is bigger than that of an average living room or bedroom.
> Although measurements took place at different levels (height) and different positions in the fire room, it cannot be stated with certainty that these measurements are representative of average conditions in the fire room at different heights. The measurements may reflect local effects.
> Although ignition sources were chosen and placed with care and the protocol was followed, there could be some (small) differences between tests.
> As with other studies that use the same methodology (experiments in a 'real' environment instead of a laboratory), there are always some phenomena or uncertainties in the data that cannot be explained. The advantage of the chosen methodology is that a good impression can be obtained.
> As has been mentioned, the limit values used to determine the possibility of escape and survivability are arbitrary. Other values could lead to different conclusions. The limit values are used in particular to provide insight into the differences for the different groups.
> In the experiments visibility was not measured. Taking this into account might lead to other results regarding the possibility of escape.

Considering these limitations, the results of the burning behaviour, possibility of escape and survivability that were measured here may differ from actual residential fires. Nevertheless, this research provides a good impression of the burning behaviour of *new and conventional chairs.*

5 Bibliography

Federation of the European Union Fire Officer Associations (FEU). (2017). *Fire safety of upholstered furniture and mattresses in the domestic area.* Arnhem.

Fire Service Academy. (2015a). *It depends.* Arnhem: Instituut Fysieke Veiligheid.

Fire Service Academy. (2015b). *Rapport Gebrand op inzicht.* Arnhem: Instituut Fysieke Veiligheid.

Fire Service Academy. (2017). *Impression tests upholstered furniture and mattresses.* Arnhem: IFV.

Fire Service Academy. (2020). *Smoke propagation in residential buildings. The main report on the field experiments conducted in a residential building with internal corridors.* Arnhem: IFV.

Fire Service Academy. (2021). *Annual overview of fatal residential fires 2020.* Arnhem: IFV.

Hadjisophocleous, G., & Mehaffey, J. (2016). Fire scenarios. In M. Hurley, *SFPE Handbook of Fire Protection Engineering* (pp. 5th ed, pp. 1262-1289). New York: Springer.

Hazebroek, J.C., Groenewegen-ter Morssche, K. Van den Dikkenberg, R. (2015). *'Het kan verkeren' – Beschrijvend onderzoek naar brandontwikkeling en overleefbaarheid.* Arnhem: Instituut Fysieke Veiligheid.

ISO 13571. (2012). *Life-threatening components of fire - Guidelines for the estimation of time to compromised tenability in fires.* Geneva: International Organization for Standardization.

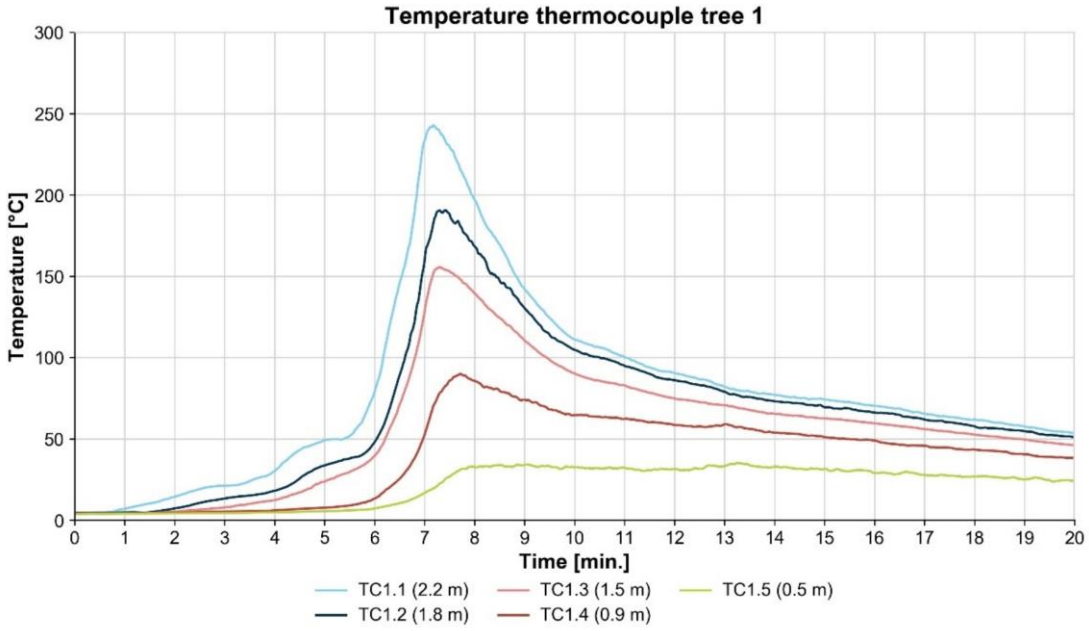
Meulenbelt, J., Vries, I. De & Joore, J.C.A. (1996). *Behandeling van acute vergiftigingen, praktische richtlijnen.* Houten: Bohn, Stafleu Van Loghum.

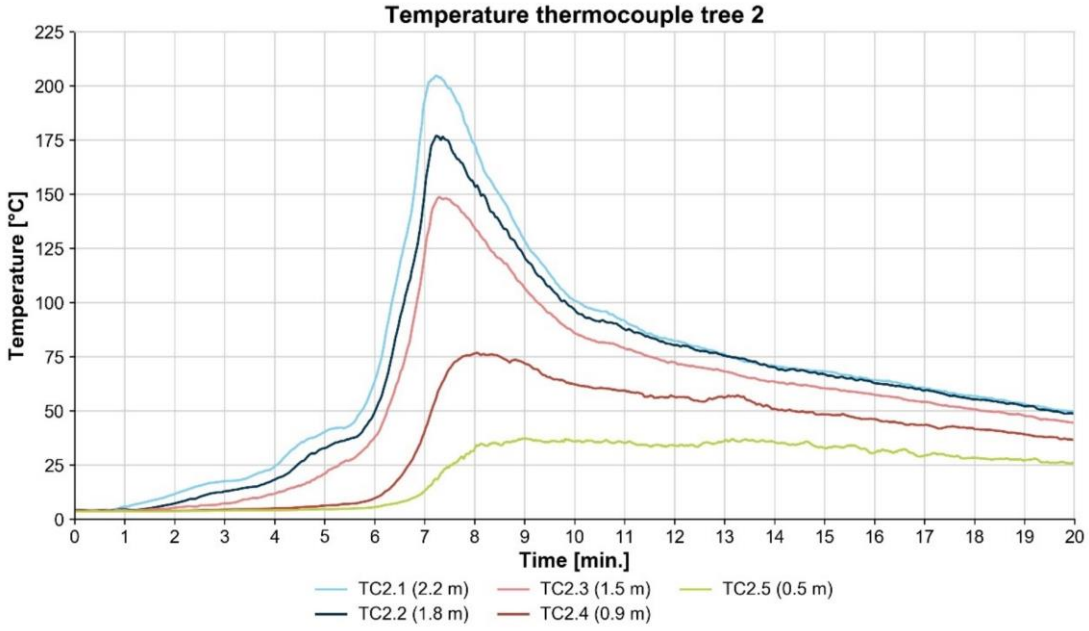
Purser, D., & McAllister, J. (2016). Assessment of Hazards to Occupants from Smoke, Toxic Gases, and Heat. In M. Hurley, *SFPE Handbook of Fire Protection Engineering* (pp. 5th ed., pp. 22308-2428). New York: Springer.

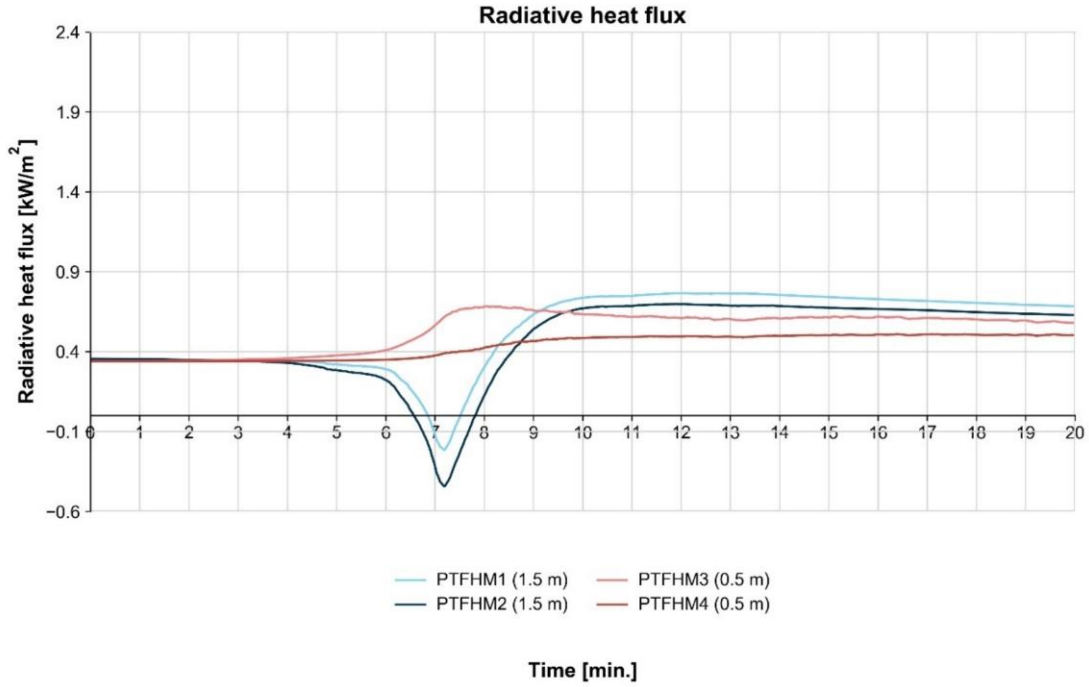
Appendix 1 Overview measured data per sensor and test

Test 1 new chair (door closed)

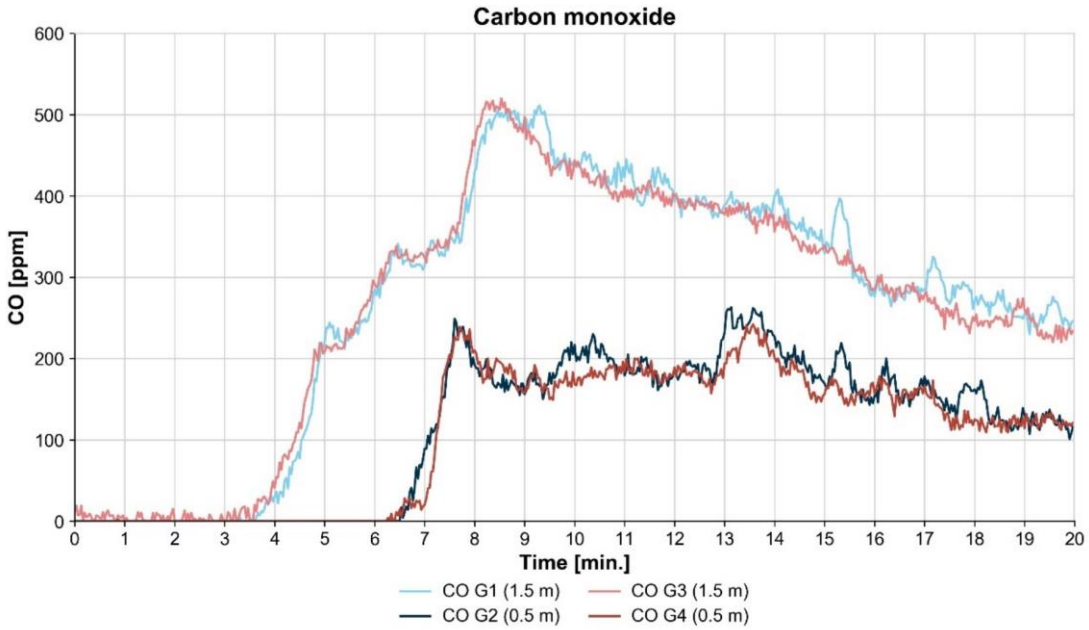
Heat

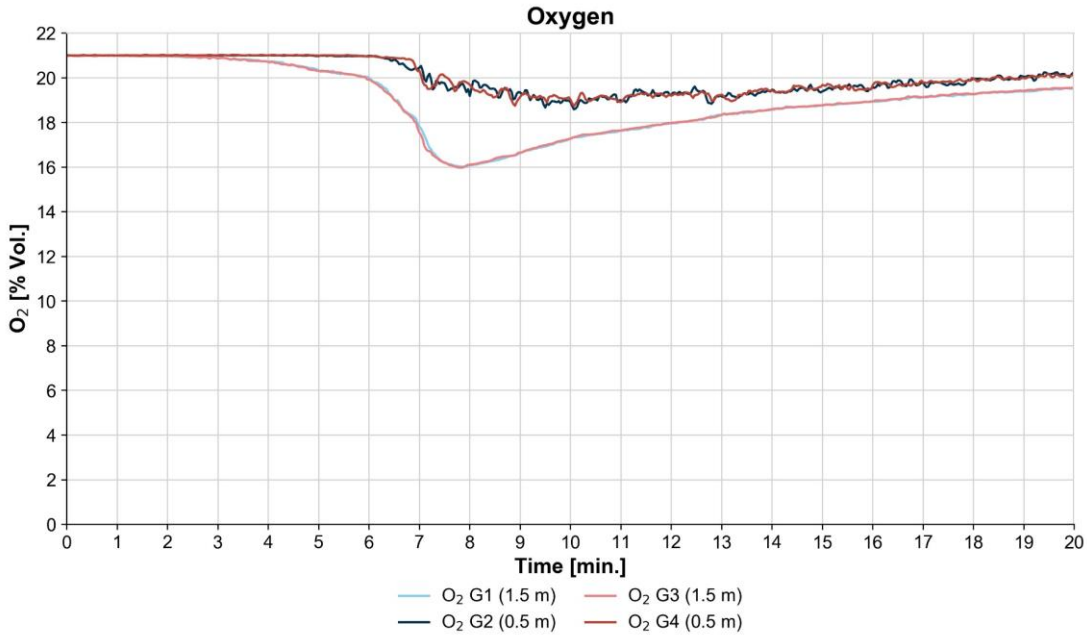


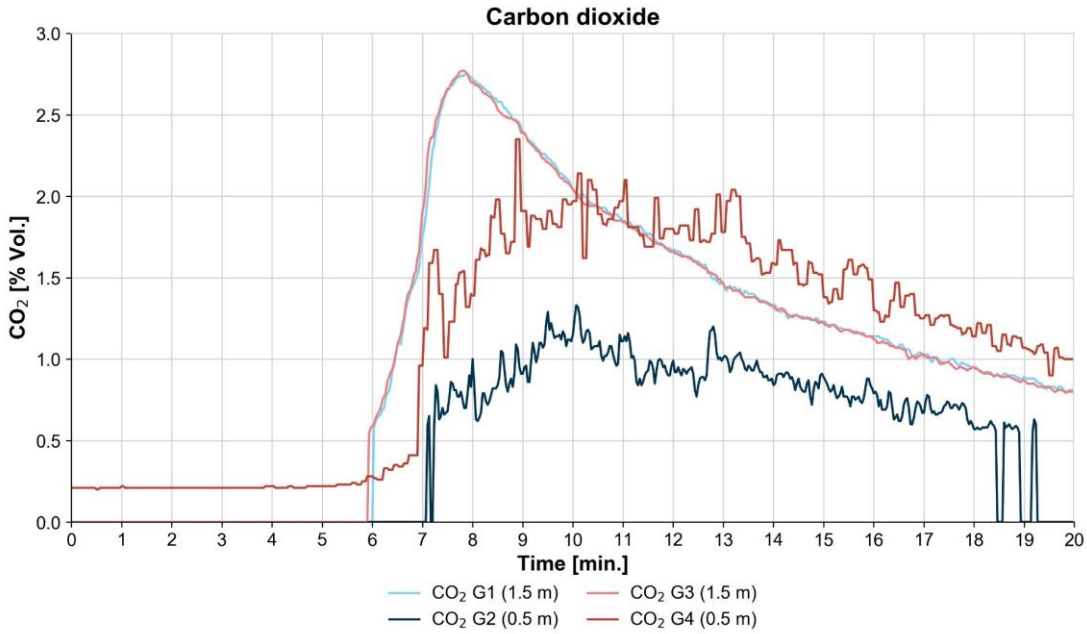


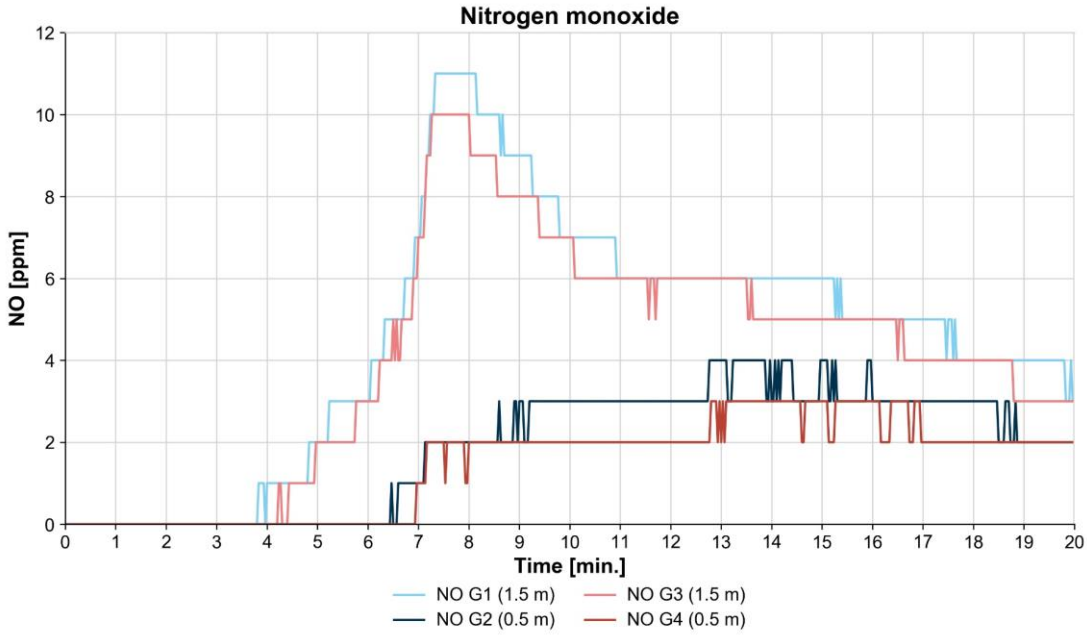

Radiative heat flux
Radiative heat flux [kW/m²]
2.4
1.9
1.4
0.9
0.4
−0.1
−0.6
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)
Time [min.]

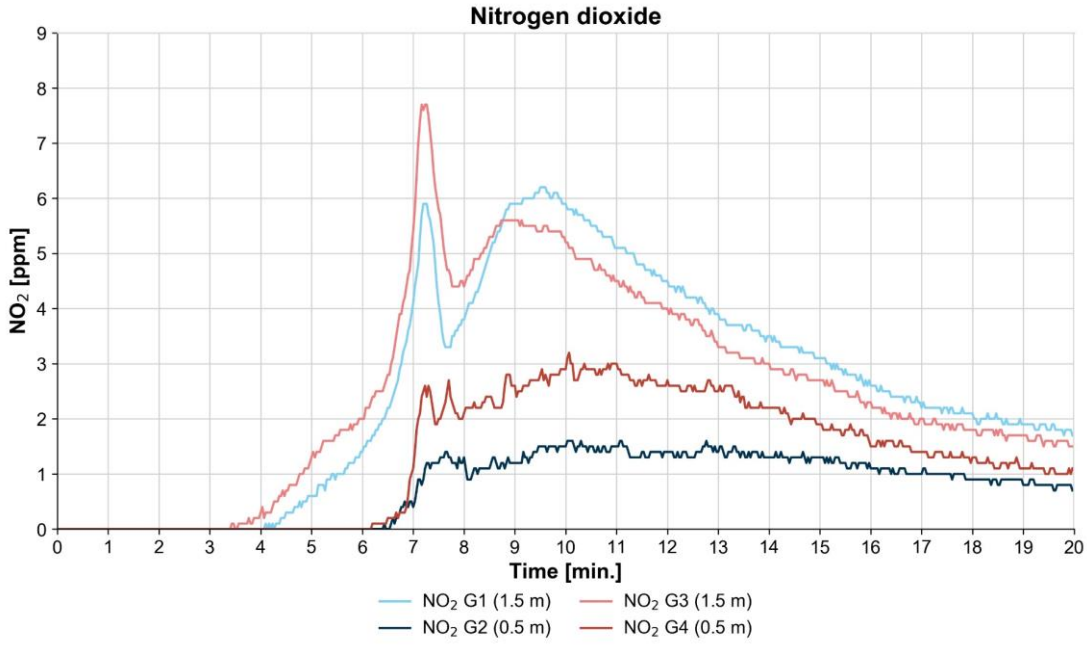
Gases

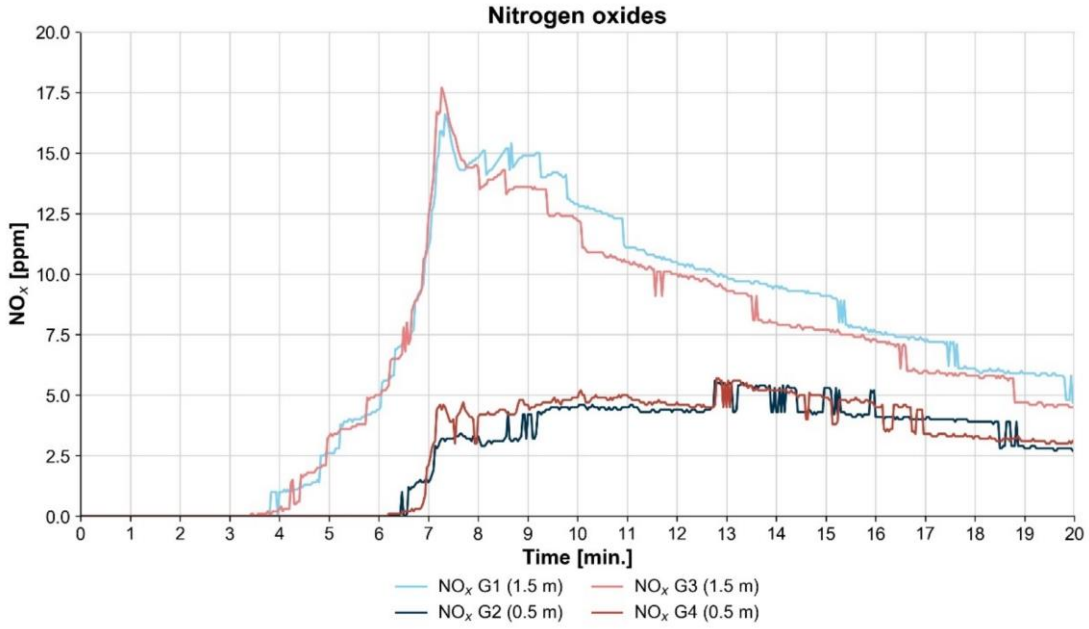

Carbon monoxide
CO [ppm]
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
O2 [% Vol.]
Time [min.]
O2 G1 (1.5 m)
O2 G3 (1.5 m)
O2 G2 (0.5 m)
O2 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 G3 (1.5 m)
NO2 G2 (0.5 m)
NO2 G4 (0.5 m)

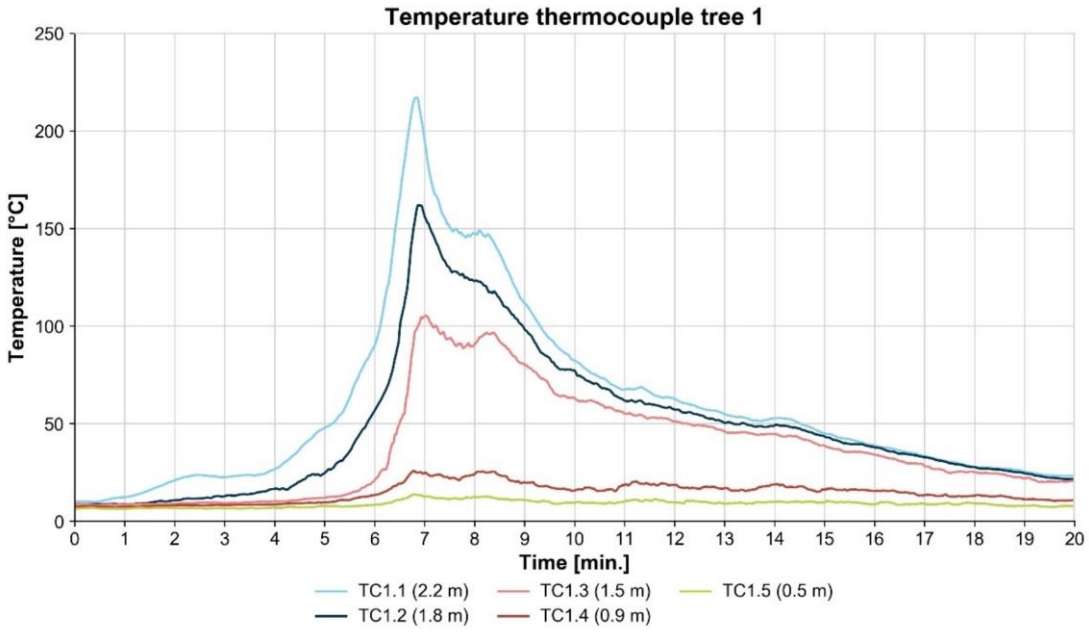

Nitrogen oxides
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
NOx [ppm]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
NOx G1 (1.5 m)
NOx G3 (1.5 m)
NOx G2 (0.5 m)
NOx G4 (0.5 m)

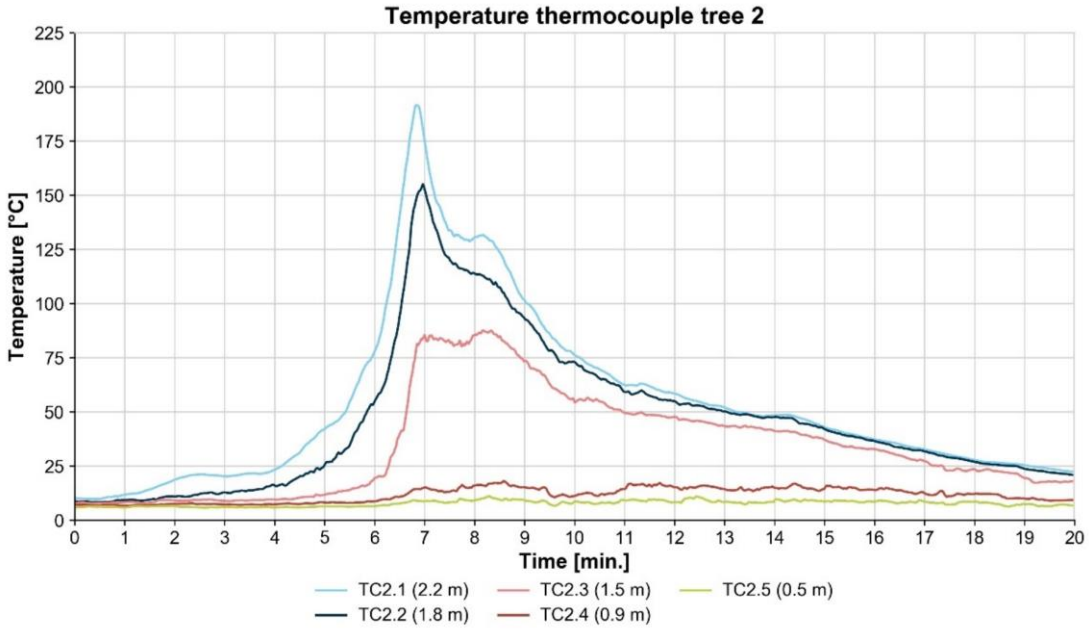
Mass loss

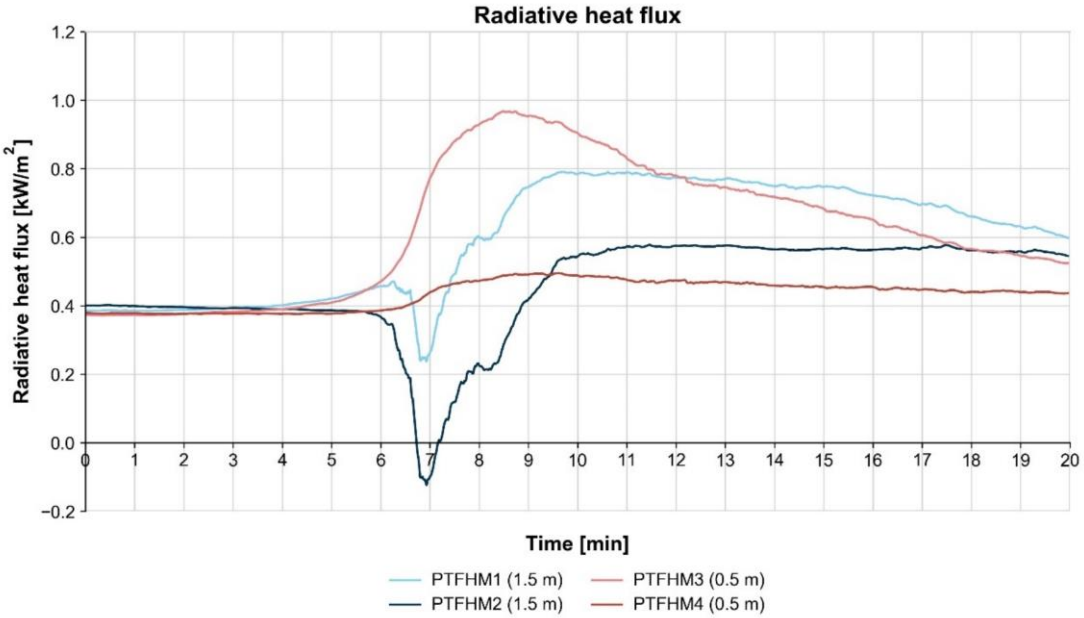

Mass loss
140
135
130
125
120
115
110
105
Mass [kg]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
WSsum

Test 2 new chair (door open)

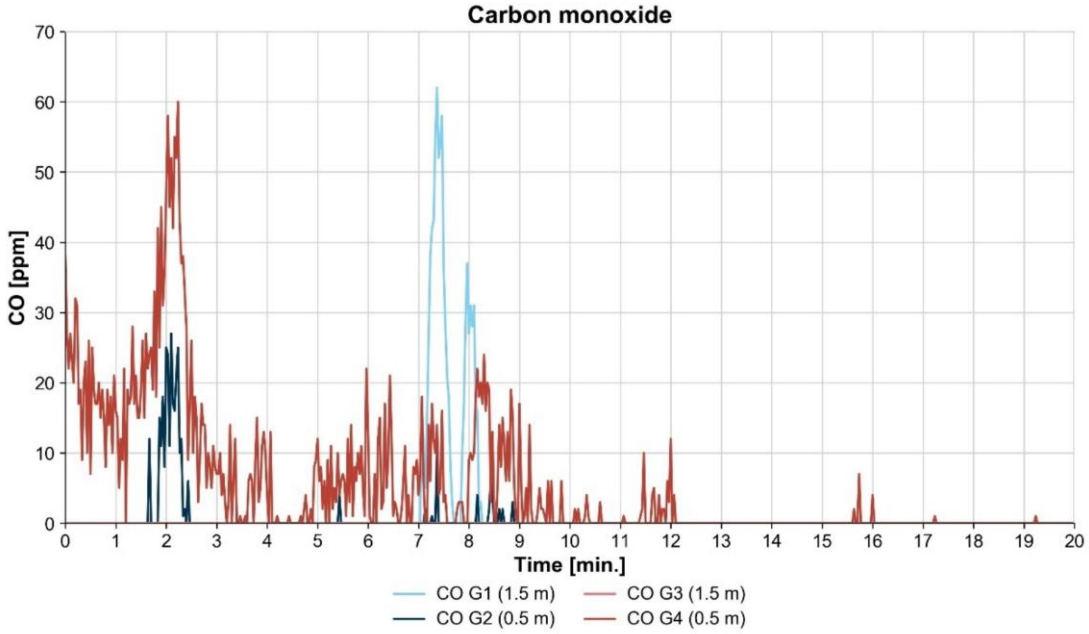
Heat

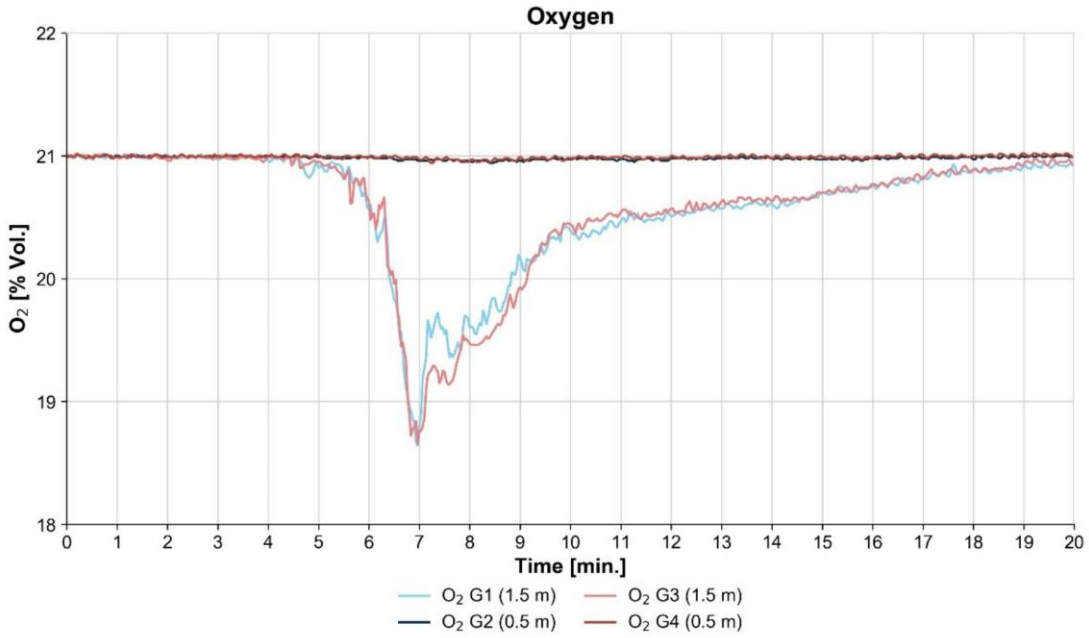


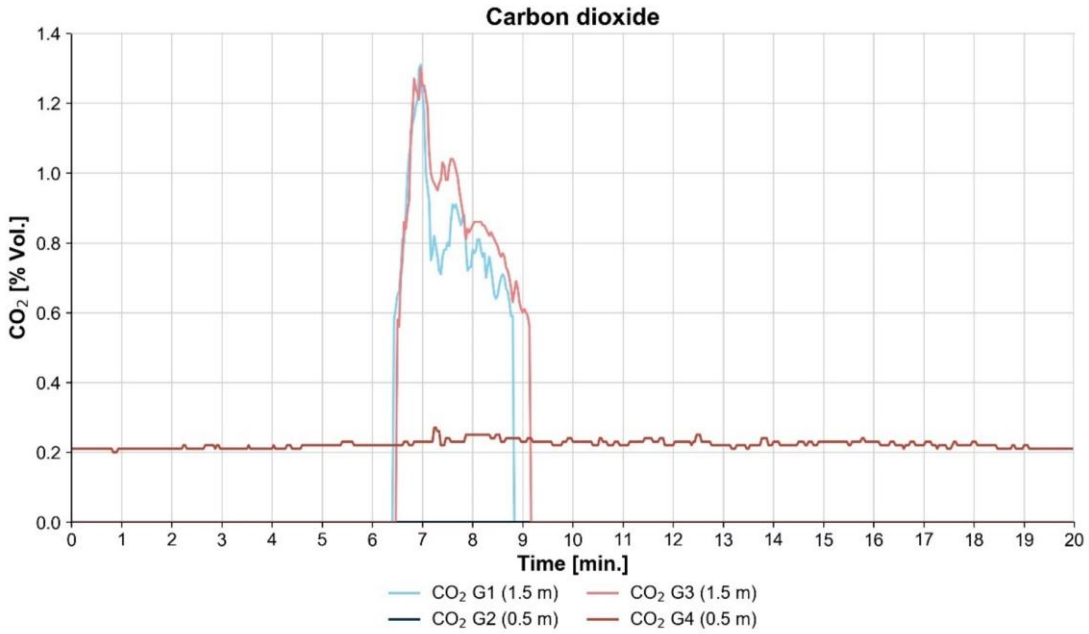


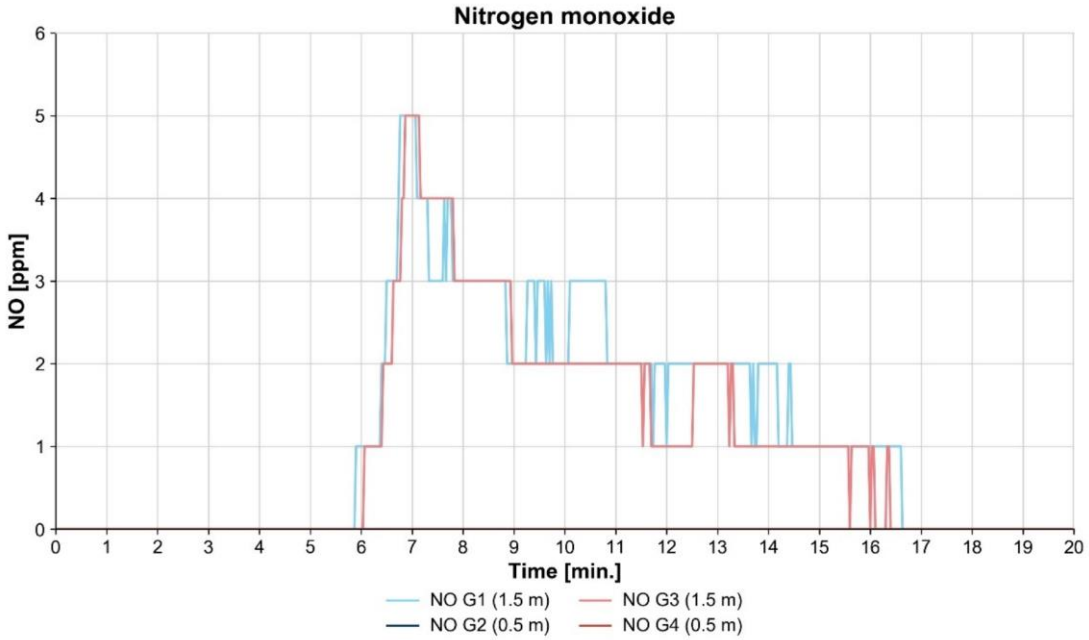

Radiative heat flux
Radiative heat flux [kW/m²]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

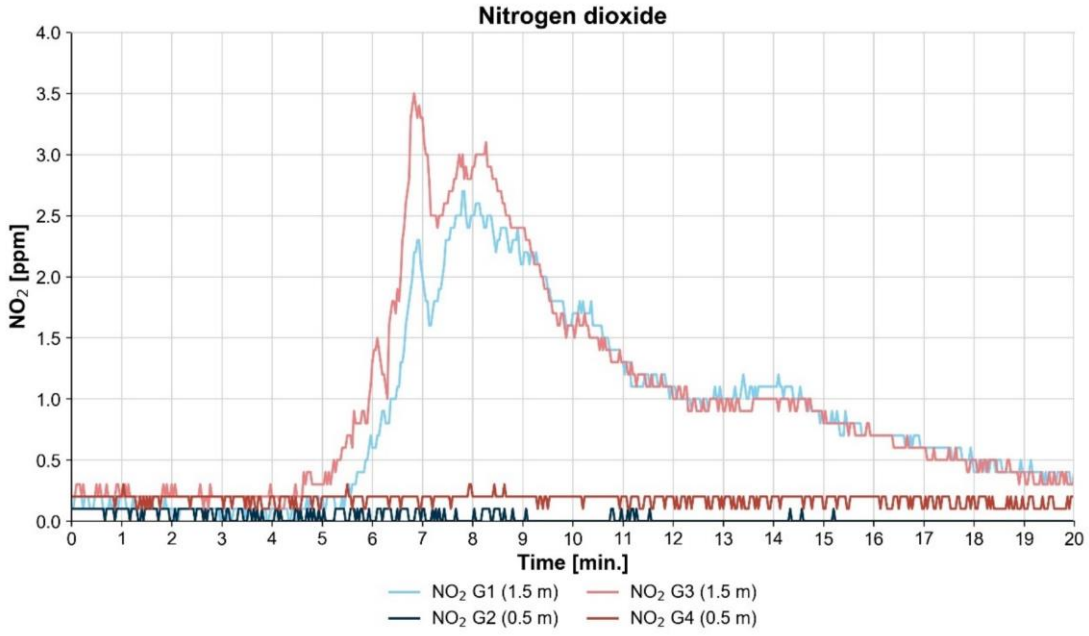
Gases

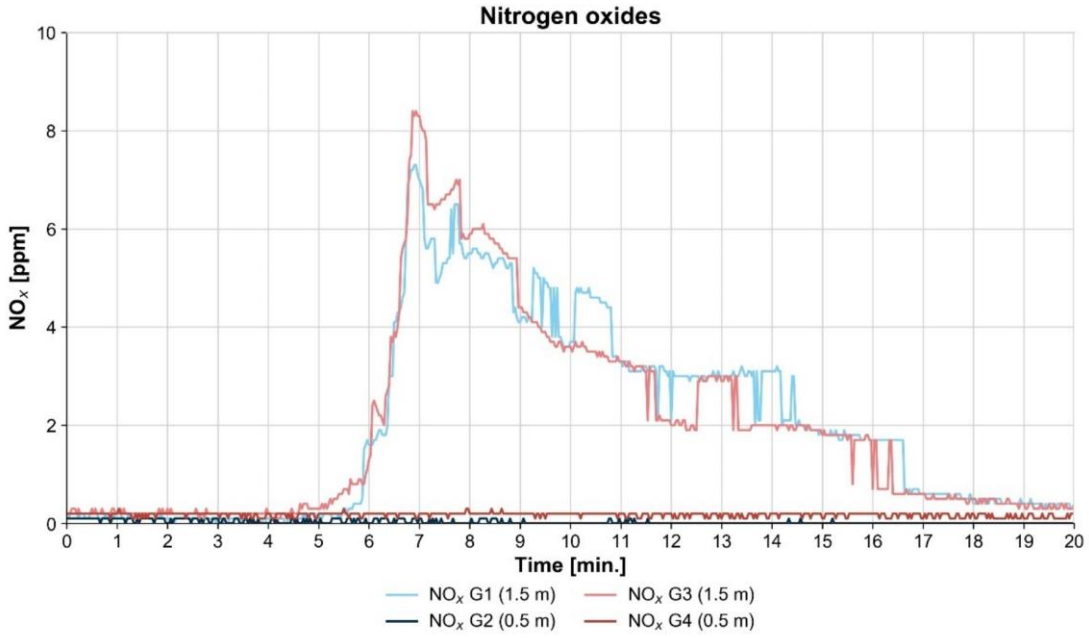

Carbon monoxide
CO [ppm]
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


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)

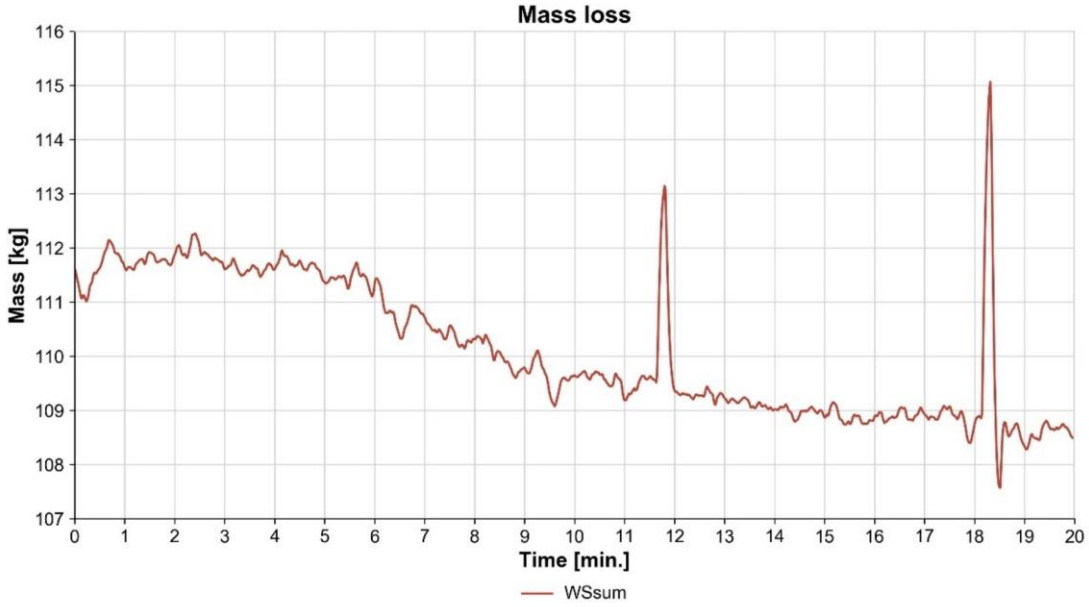

Carbon dioxide
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CO2 [% Vol.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO2 G1 (1.5 m)
CO2 G3 (1.5 m)
CO2 G2 (0.5 m)
CO2 G4 (0.5 m)


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

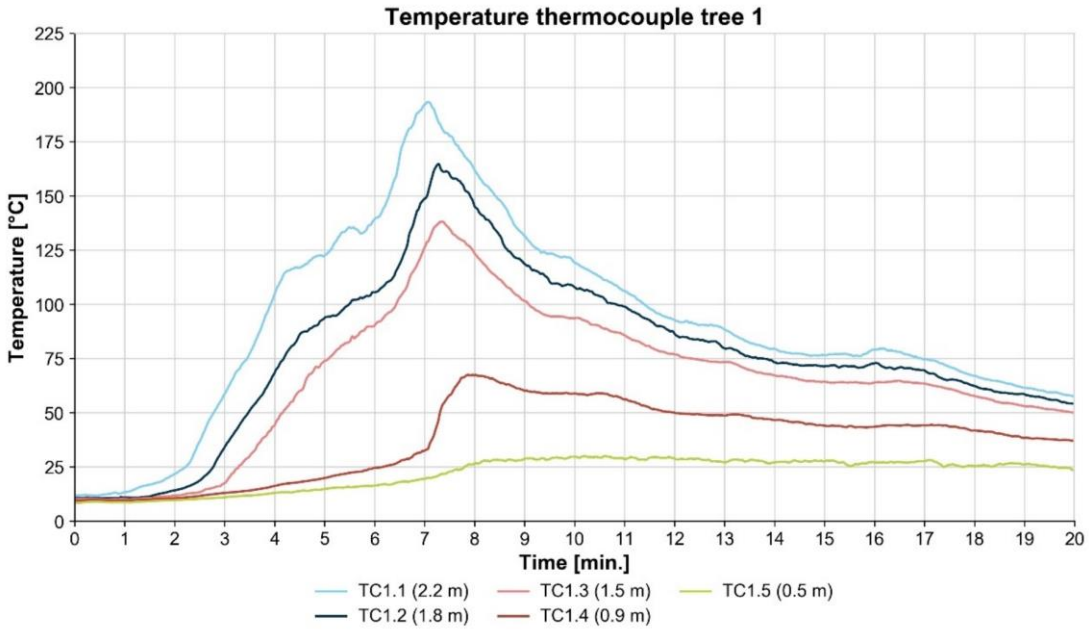

Nitrogen oxides
NOx [ppm]
Time [min.]
NOx G1 (1.5 m)
NOx G3 (1.5 m)
NOx G2 (0.5 m)
NOx G4 (0.5 m)

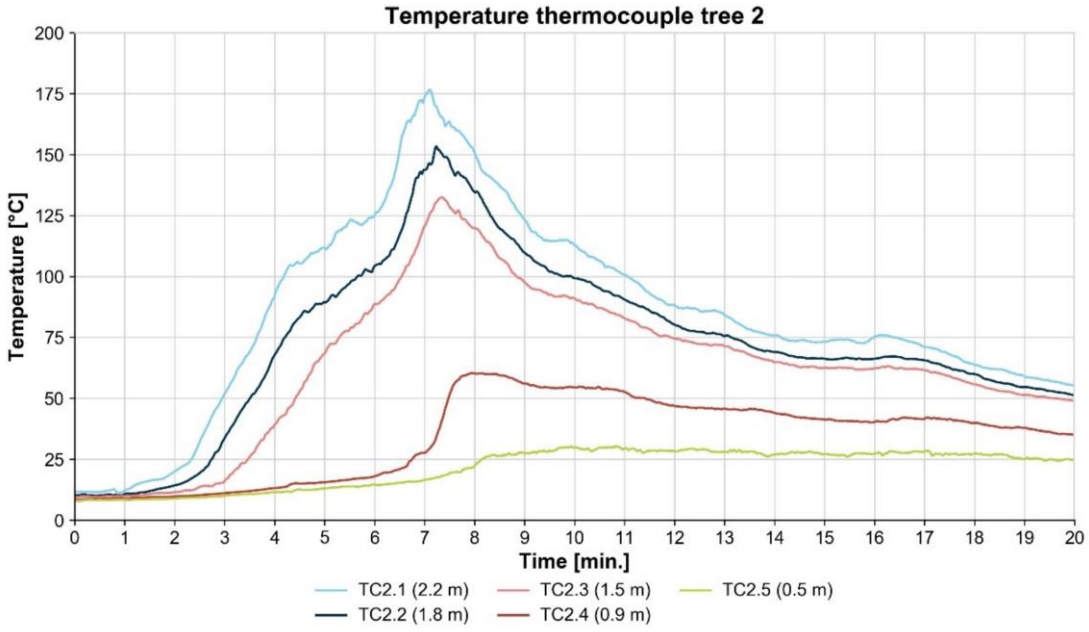
Mass loss

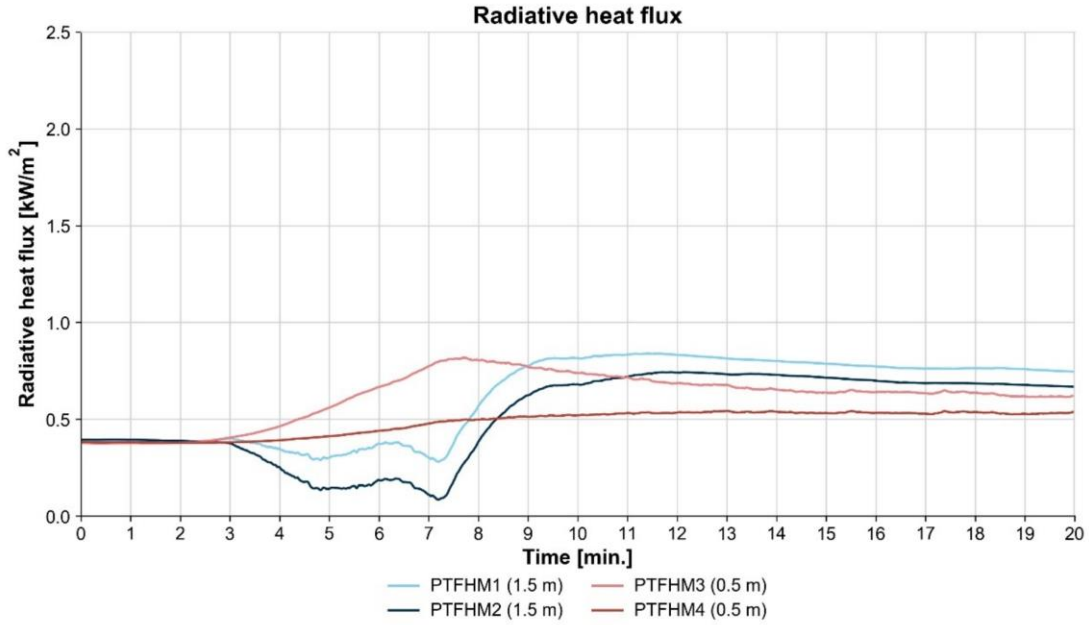

Mass loss
Mass [kg]
Time [min.]
WSsum

Test 3 conventional chair (door closed)

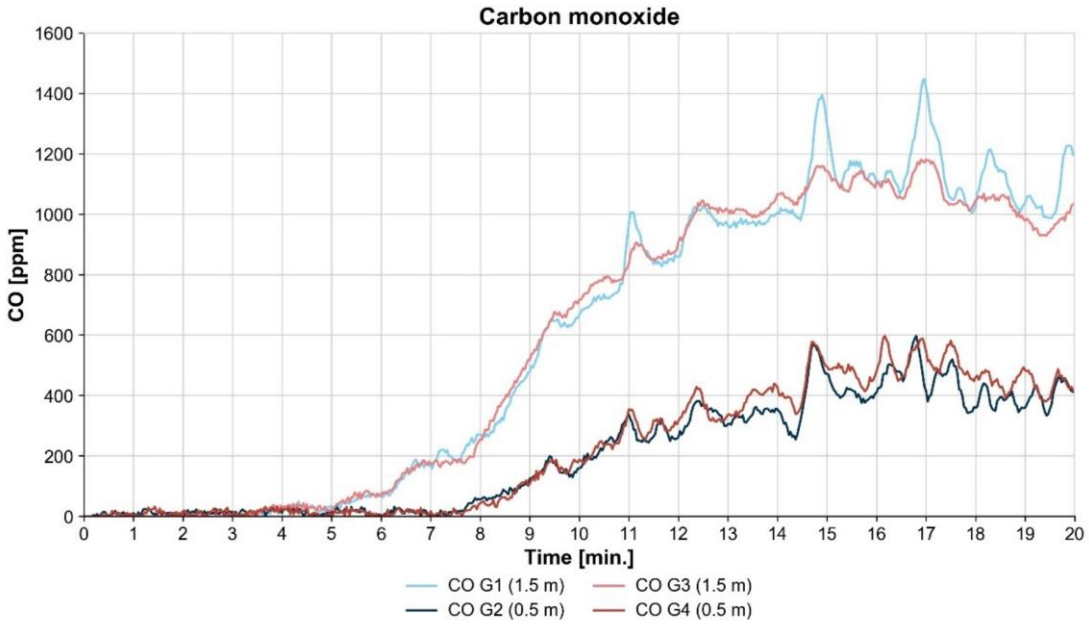
Heat

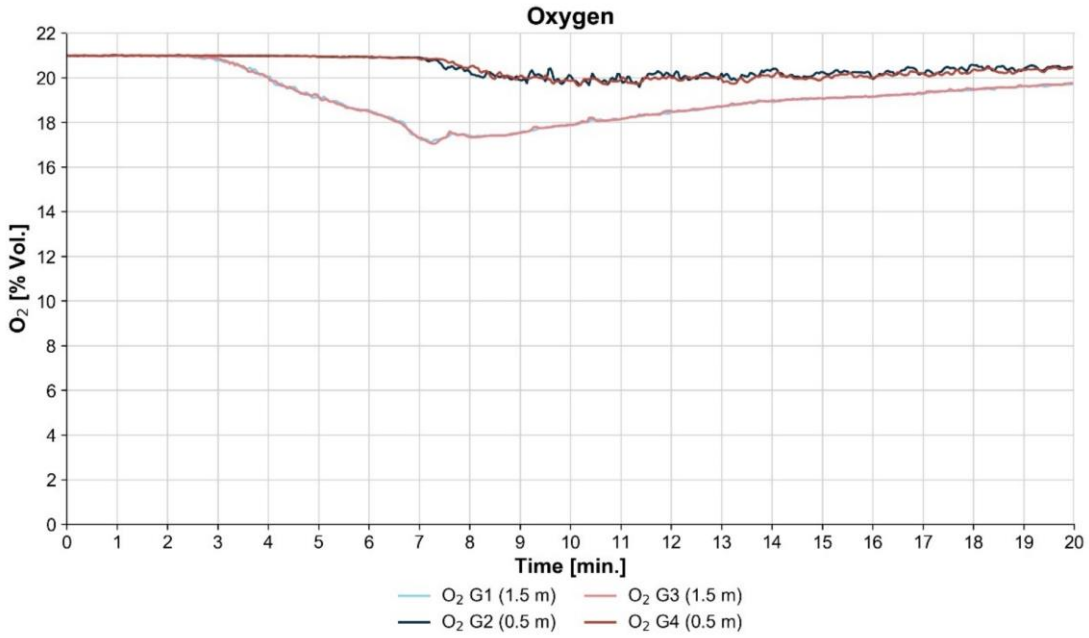


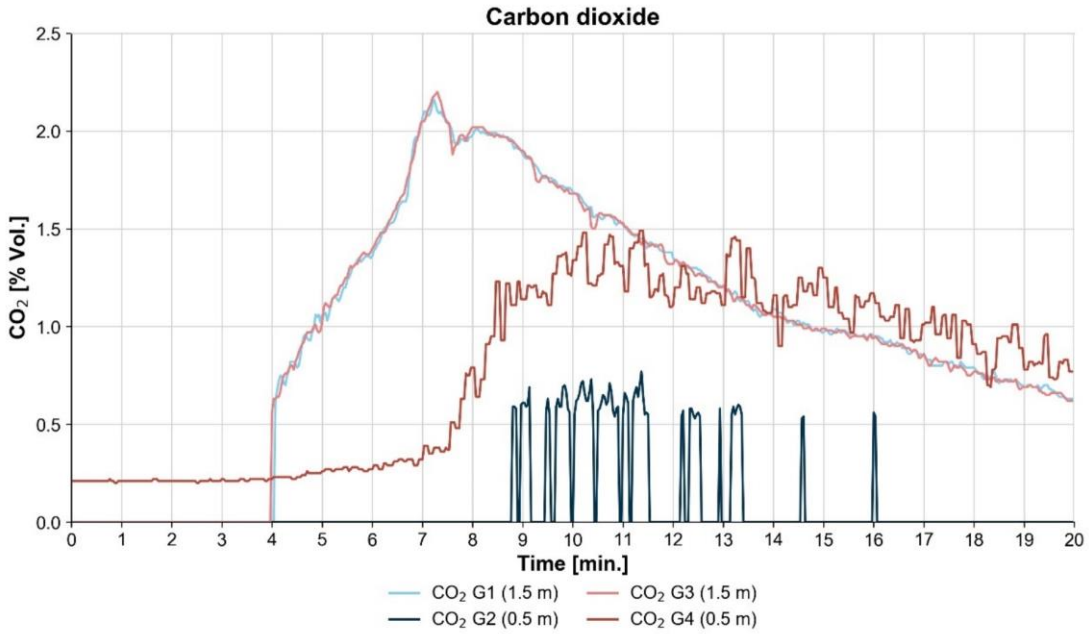


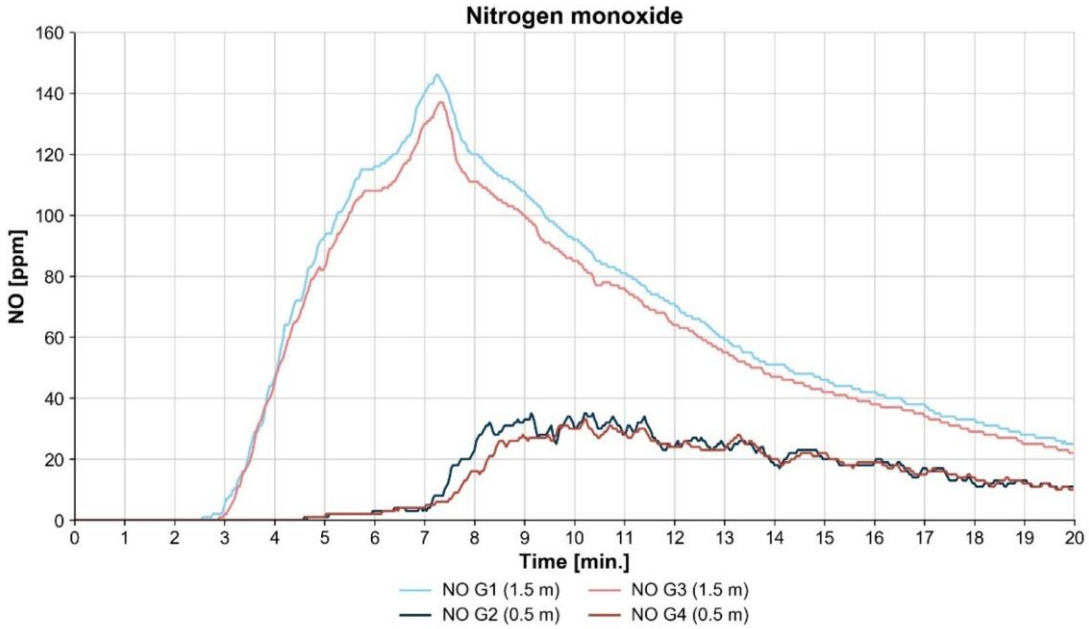

Radiative heat flux
Radiative heat flux [kW/m²]
2.5
2.0
1.5
1.0
0.5
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

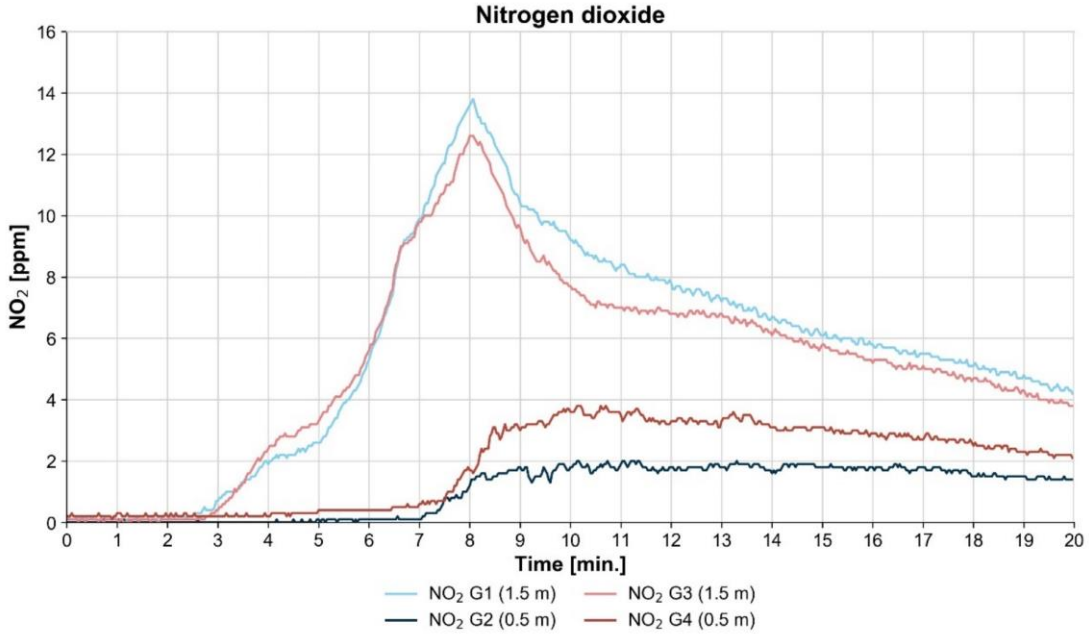
Gases

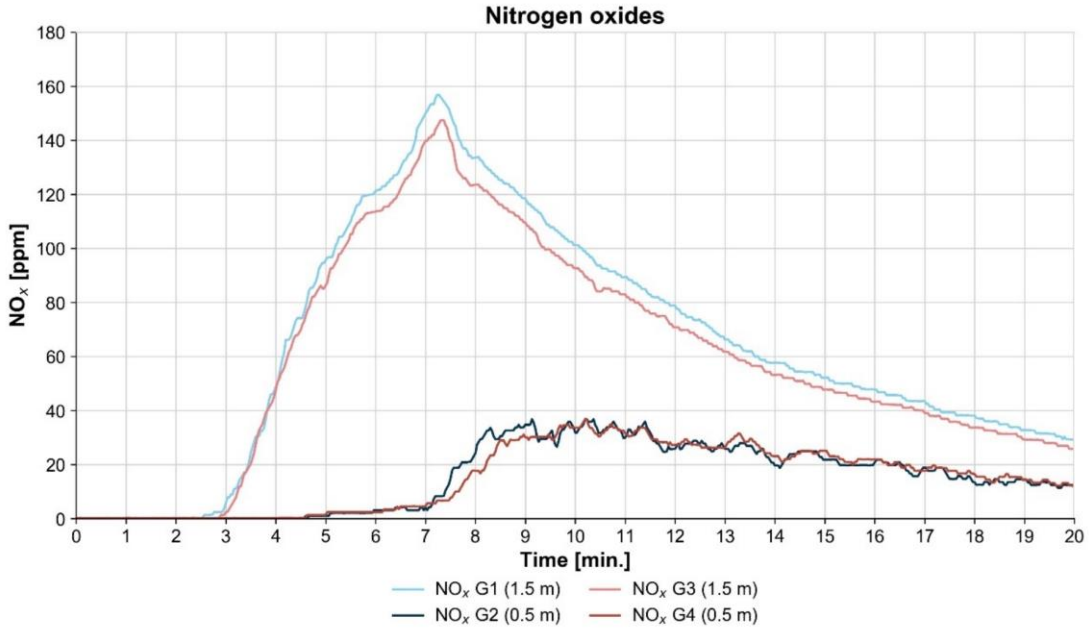

Carbon monoxide
CO [ppm]
1600
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
O2 [% Vol.]
Time [min.]
O2 G1 (1.5 m)
O2 G3 (1.5 m)
O2 G2 (0.5 m)
O2 G4 (0.5 m)

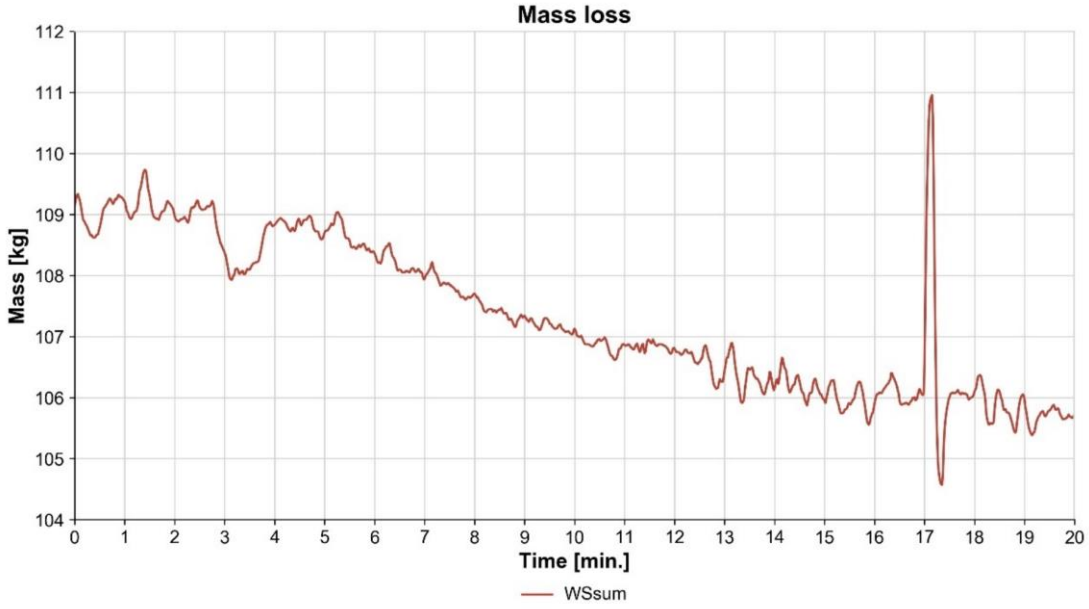

Carbon dioxide
CO2 [% Vol.]
Time [min.]
CO2 G1 (1.5 m)
CO2 G3 (1.5 m)
CO2 G2 (0.5 m)
CO2 G4 (0.5 m)


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 G3 (1.5 m)
NO2 G2 (0.5 m)
NO2 G4 (0.5 m)

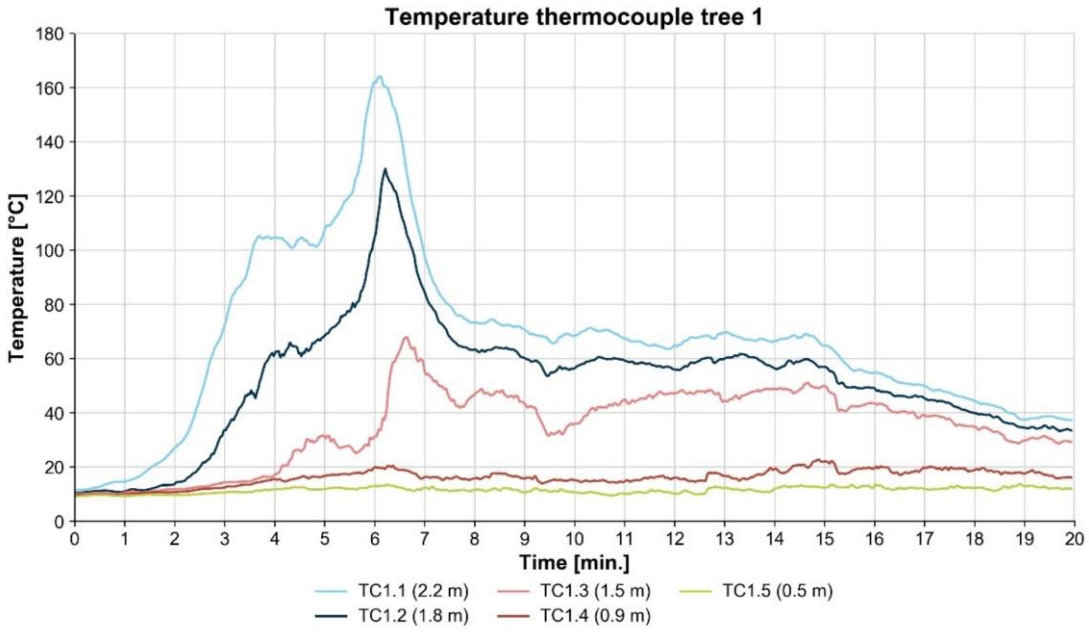

Nitrogen oxides
NO_x [ppm]
Time [min.]
NO_x G1 (1.5 m)
NO_x G3 (1.5 m)
NO_x G2 (0.5 m)
NO_x G4 (0.5 m)

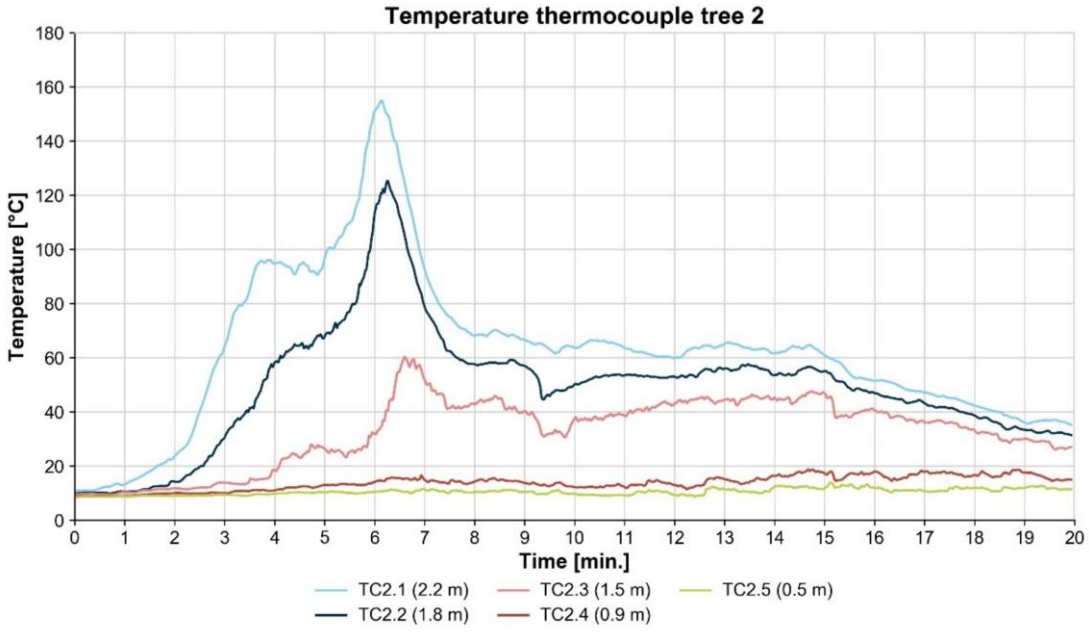
Mass loss

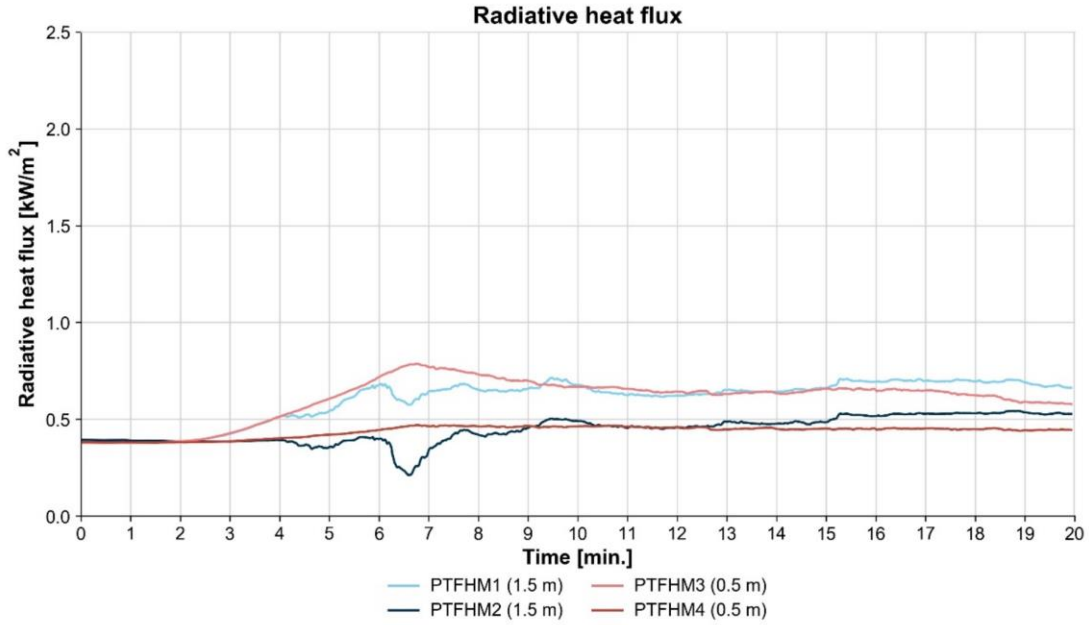

Mass loss
Mass [kg]
Time [min.]
WSsum

Test 4 conventional chair (door open)

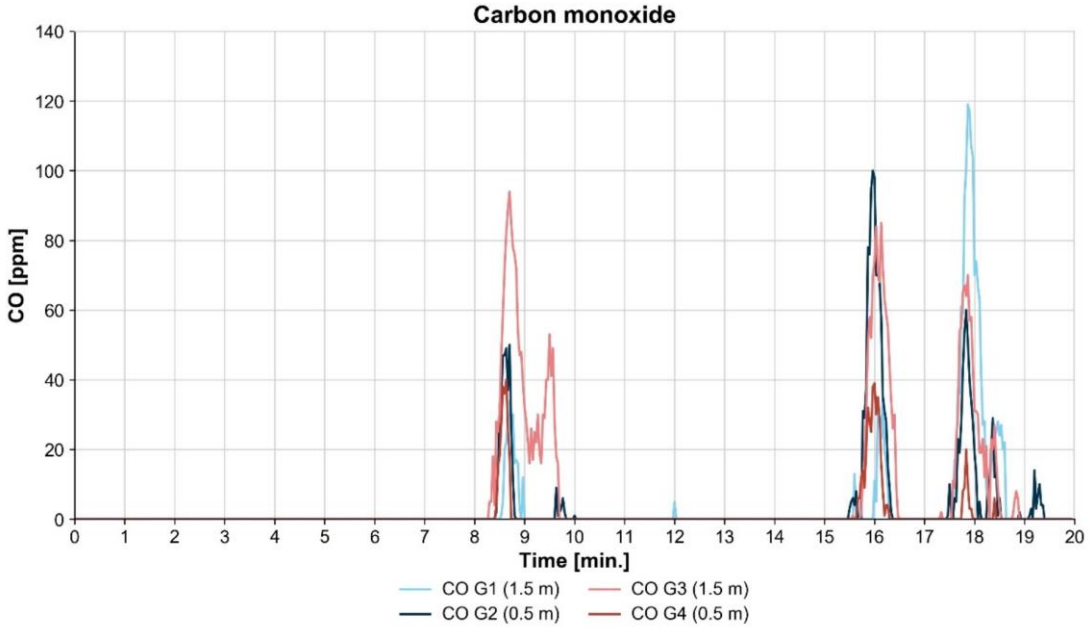
Heat

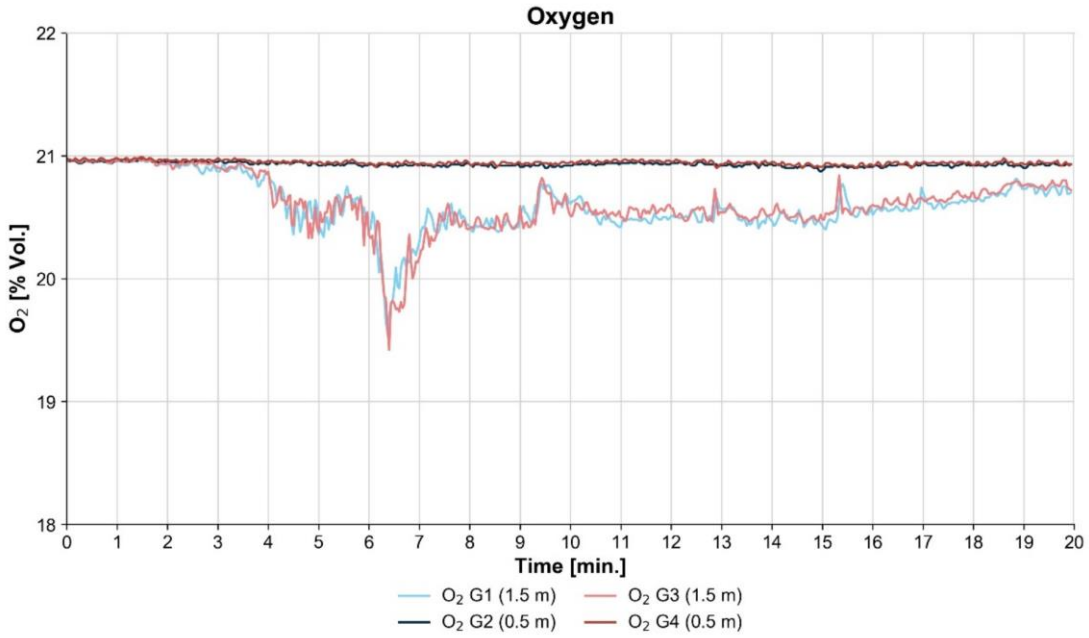


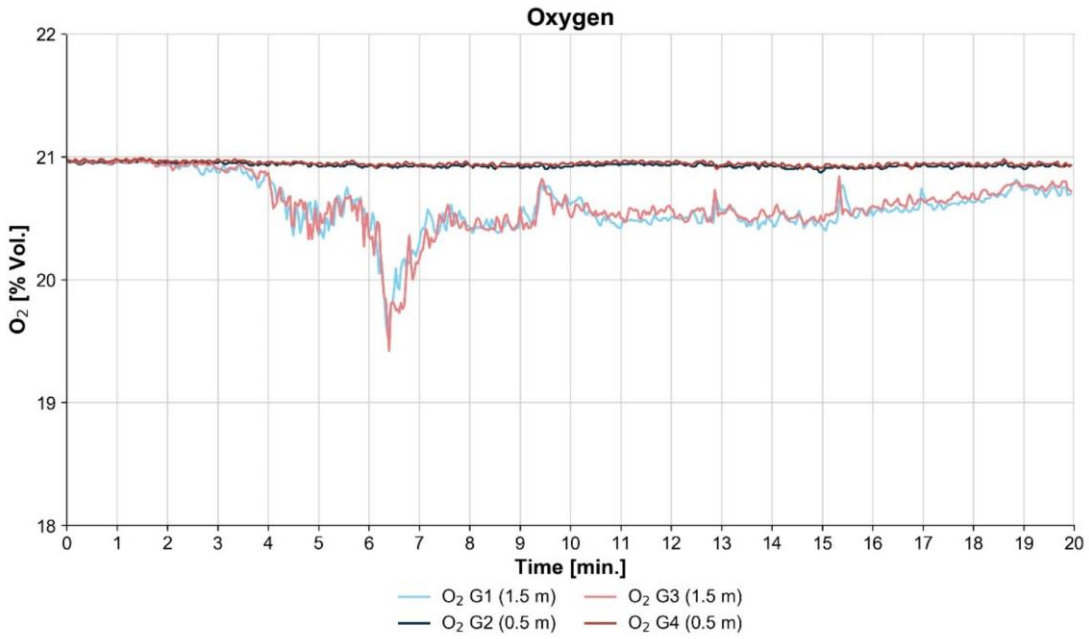


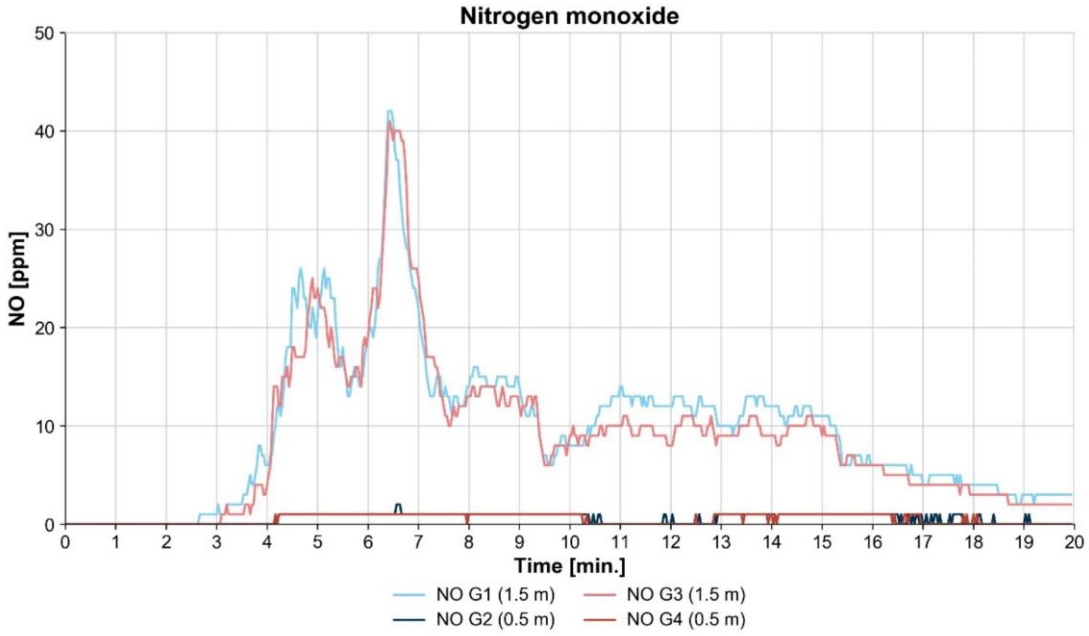

Radiative heat flux
Radiative heat flux [kW/m²]
2.5
2.0
1.5
1.0
0.5
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

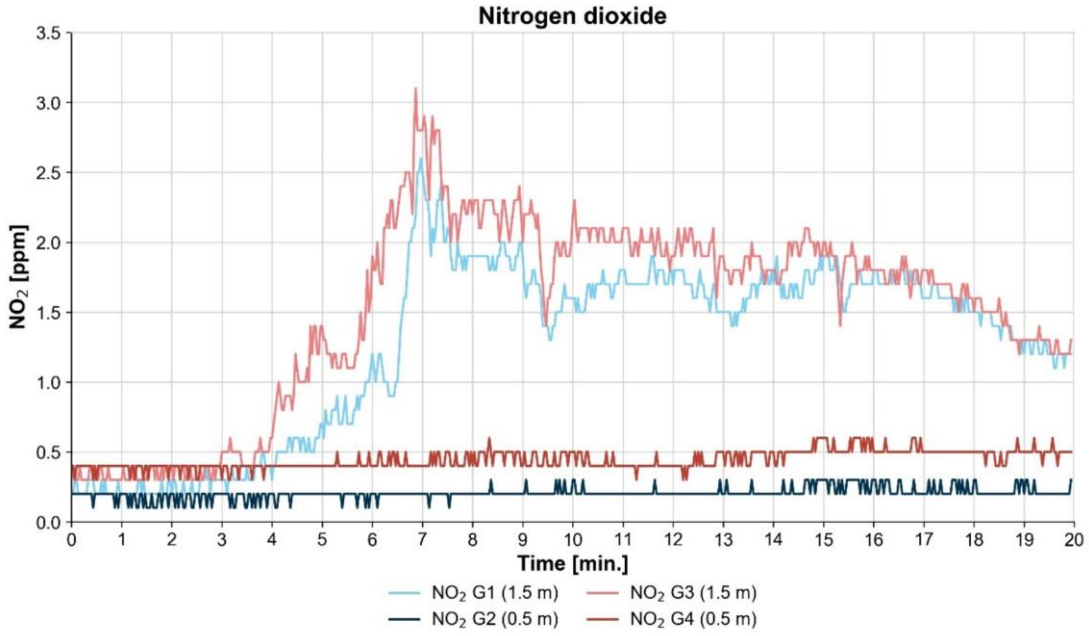
Gases

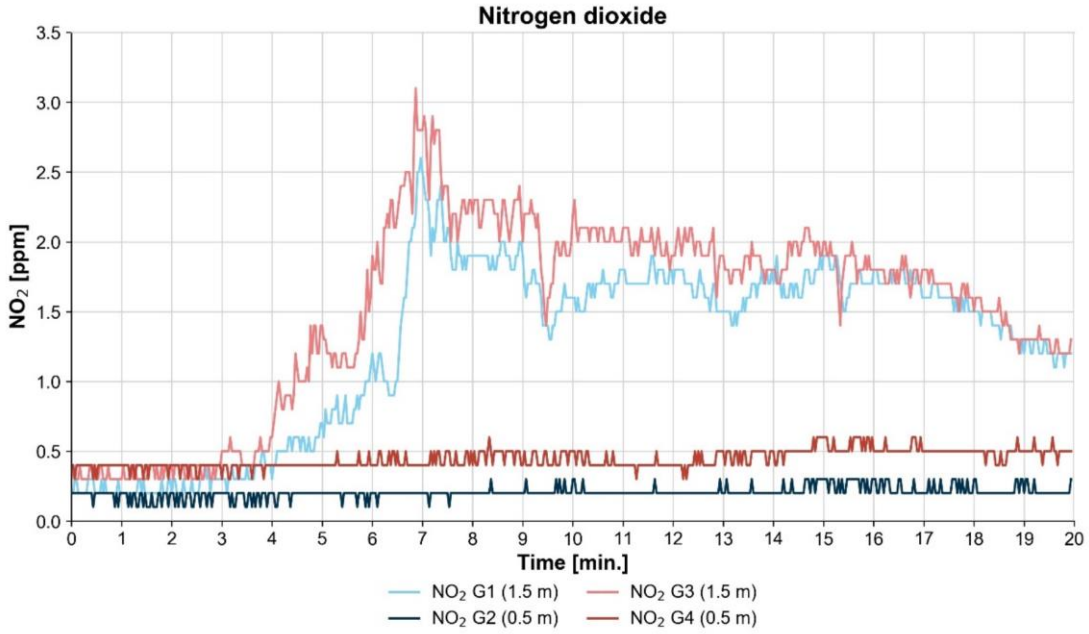

Carbon monoxide
CO [ppm]
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


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)

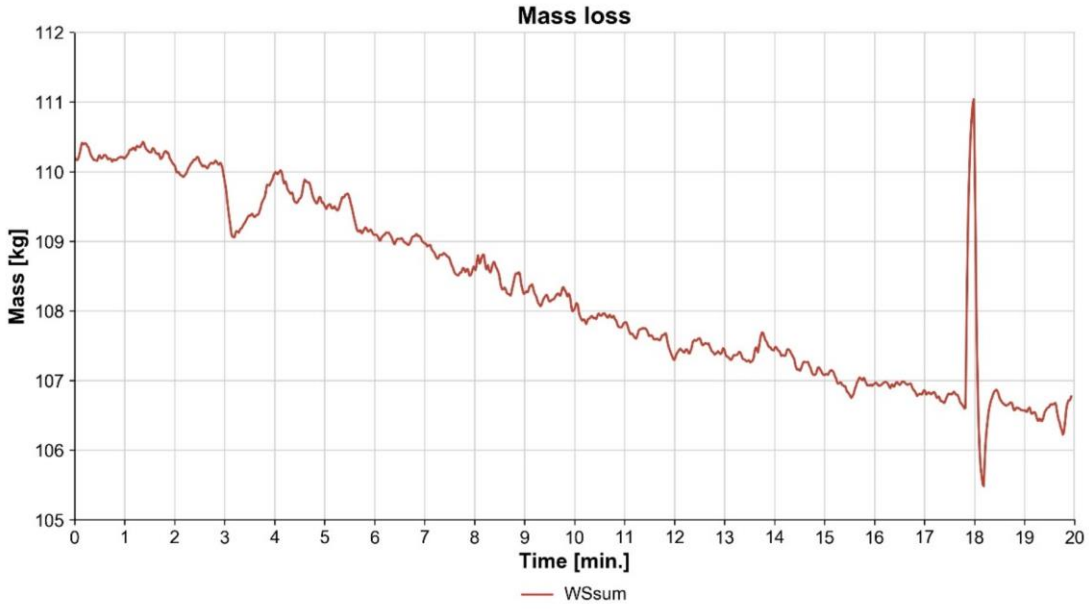

Oxygen
22
21
20
19
18
O2 [% Vol.]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Time [min.]
O2 G1 (1.5 m)
O2 G3 (1.5 m)
O2 G2 (0.5 m)
O2 G4 (0.5 m)


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 G3 (1.5 m)
NO2 G2 (0.5 m)
NO2 G4 (0.5 m)


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

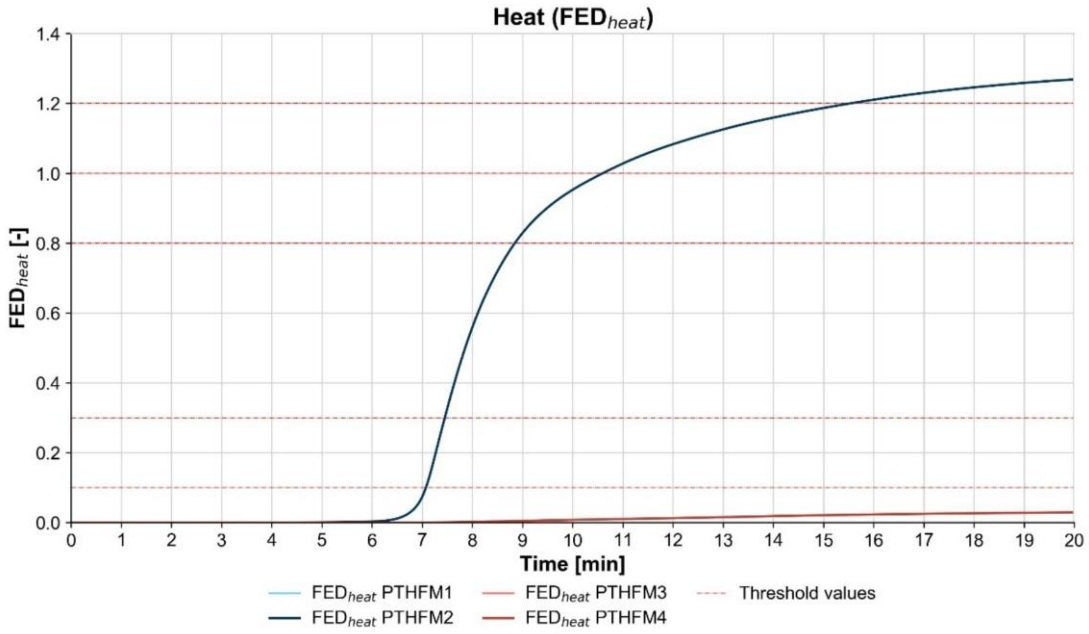
Mass loss


Mass loss
Mass [kg]
Time [min.]
WSsum

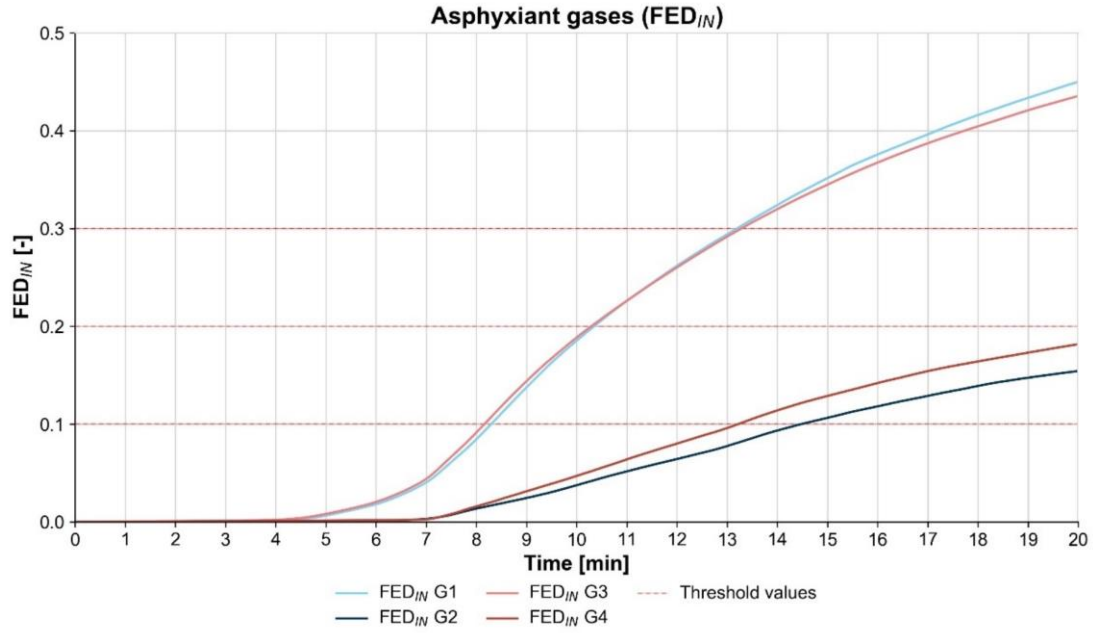
Appendix 2 Overview of the development of the possibility of escape and survivability for the different methods for each measurement location and test

Test 1 new chair (door closed)

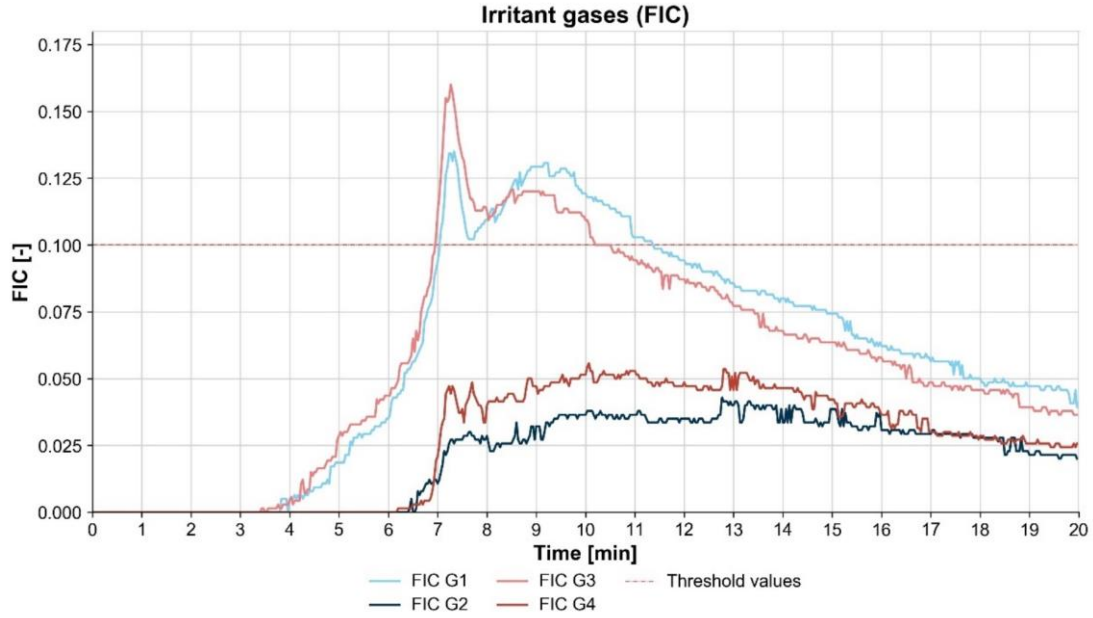
FED for heat



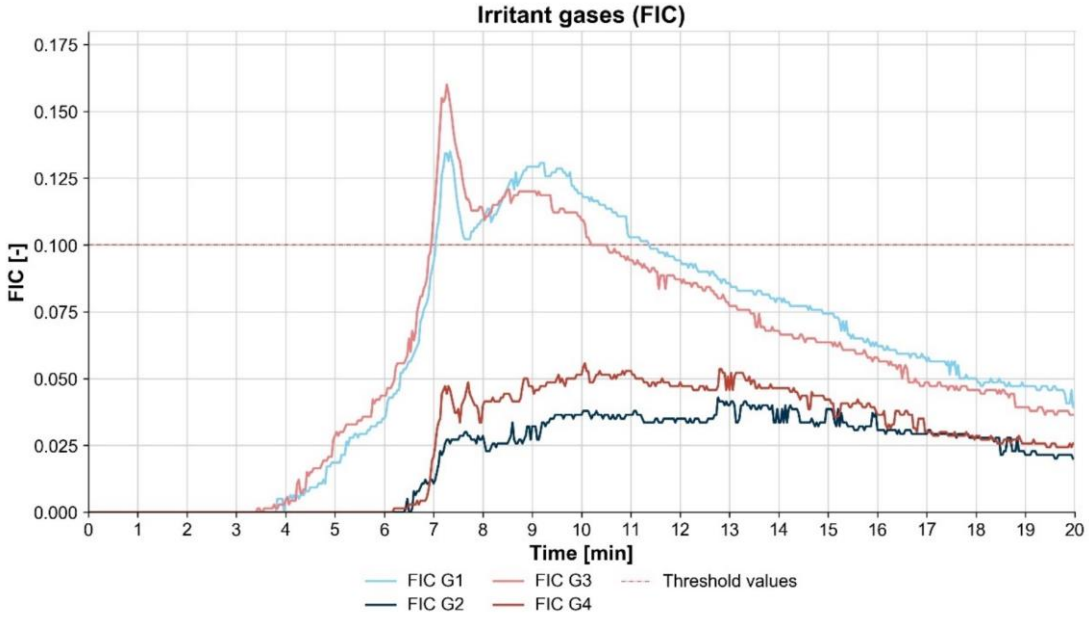
FED for asphyxiant gases



FIC for irritant gases

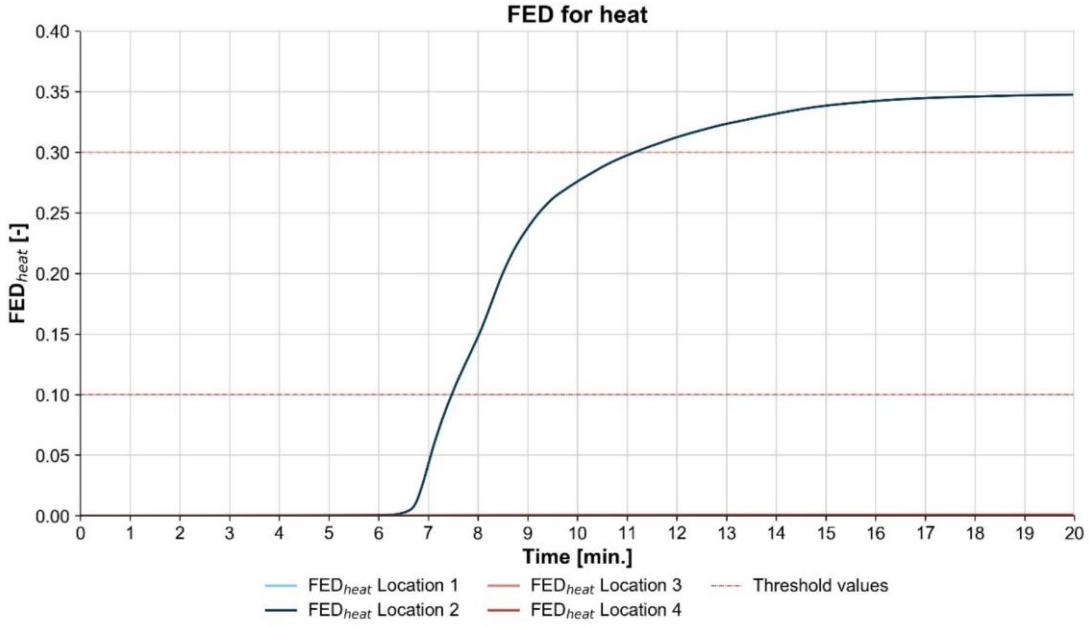


FLD for irritant gases

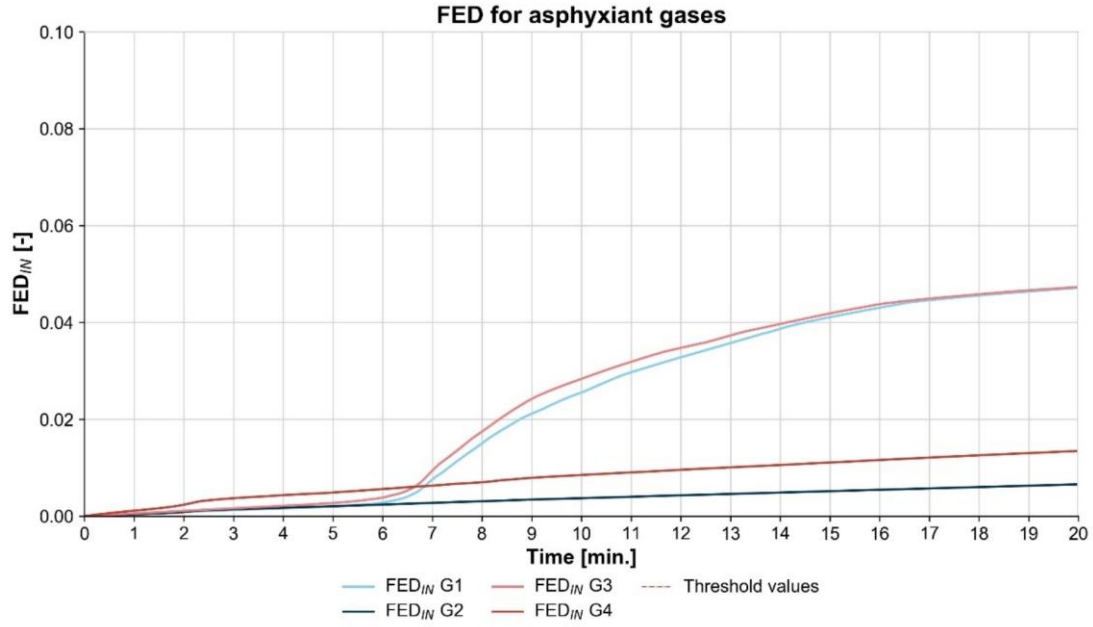


Test 2 new chair (door open)

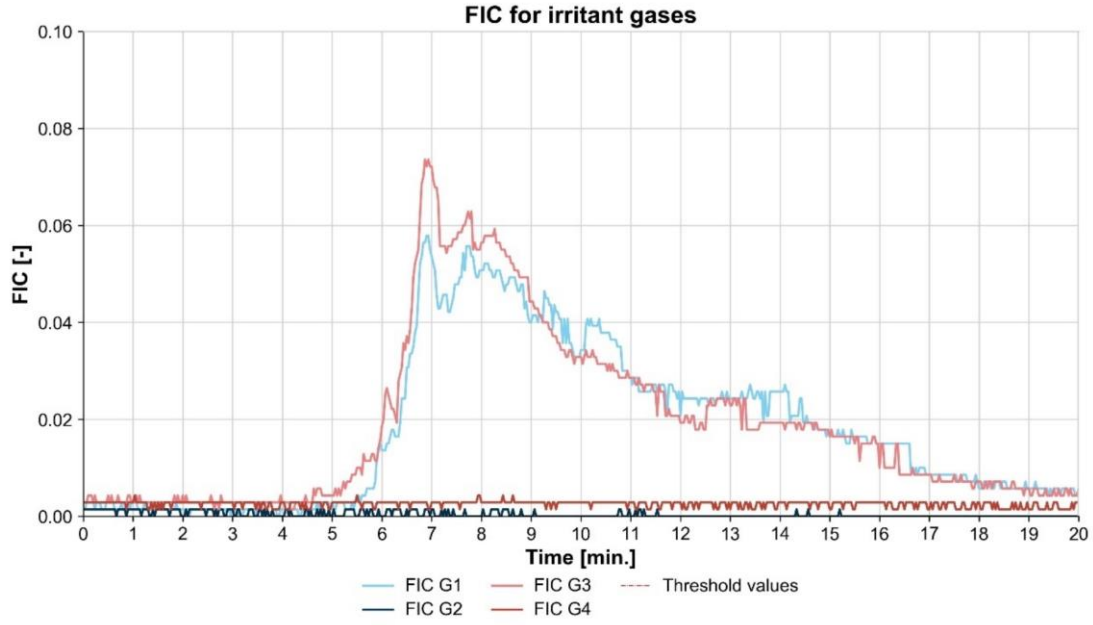
FED for heat



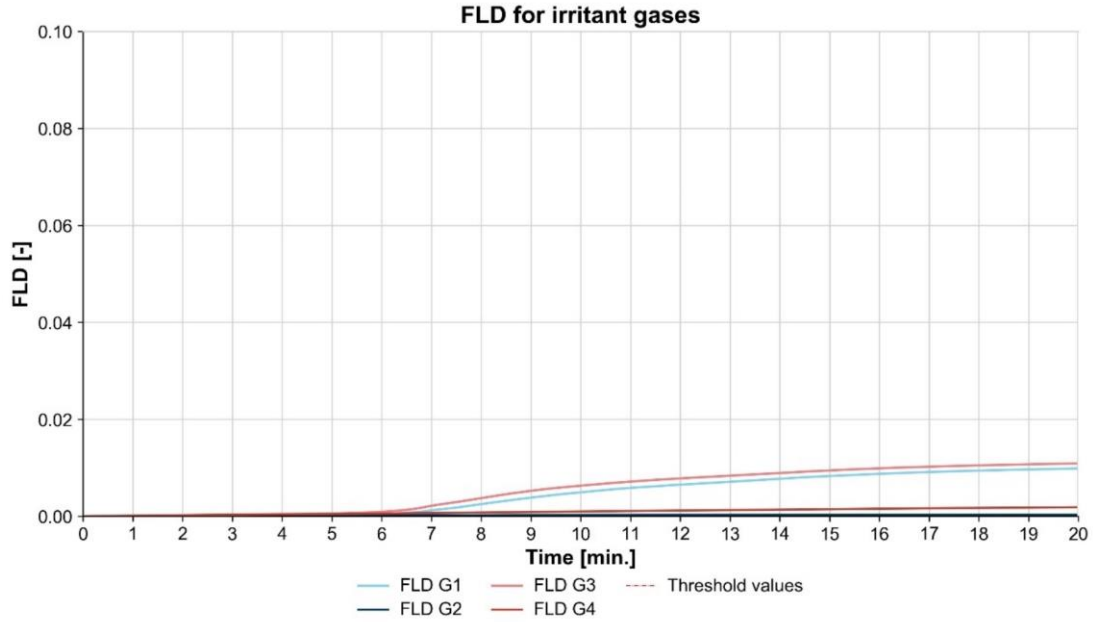
FED for asphyxiant gases



FIC for irritant gases

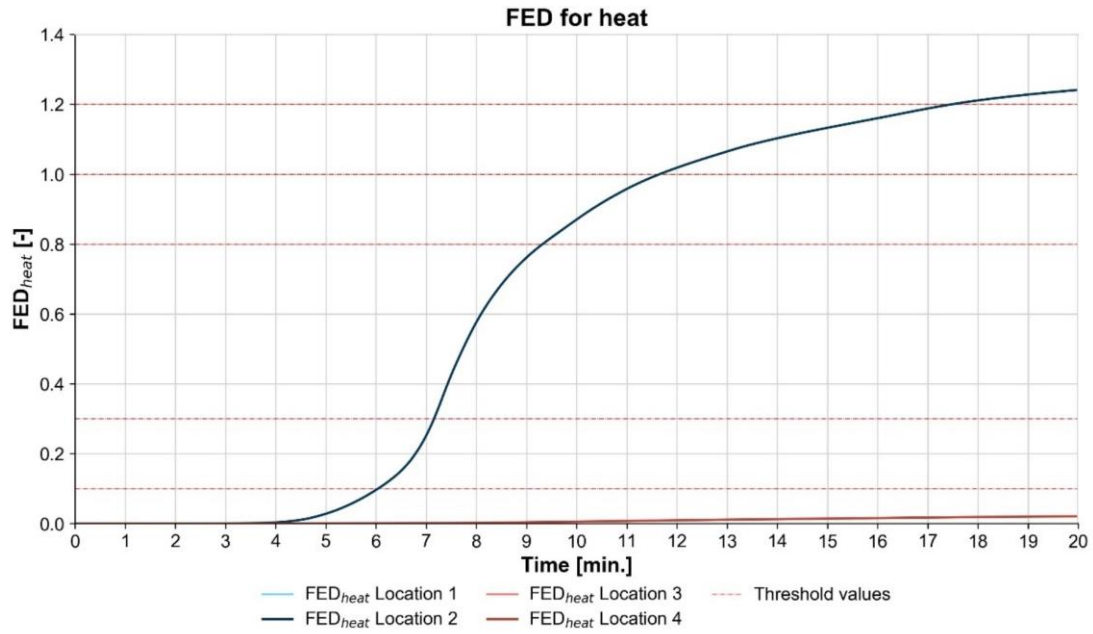


FLD for irritant gases

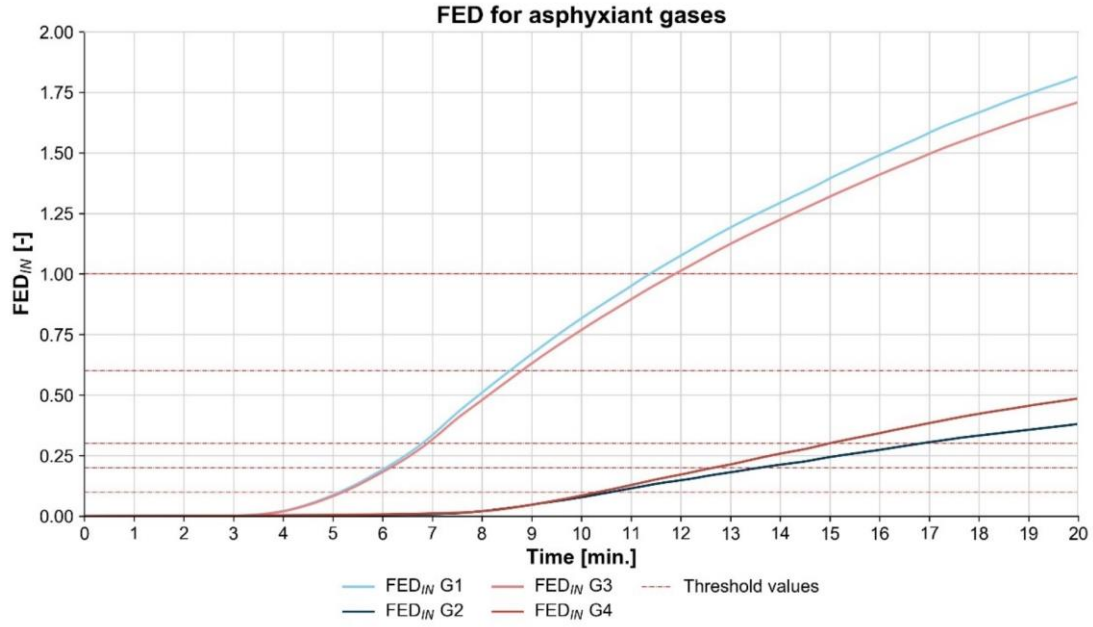


Test 3 conventional chair (door closed)

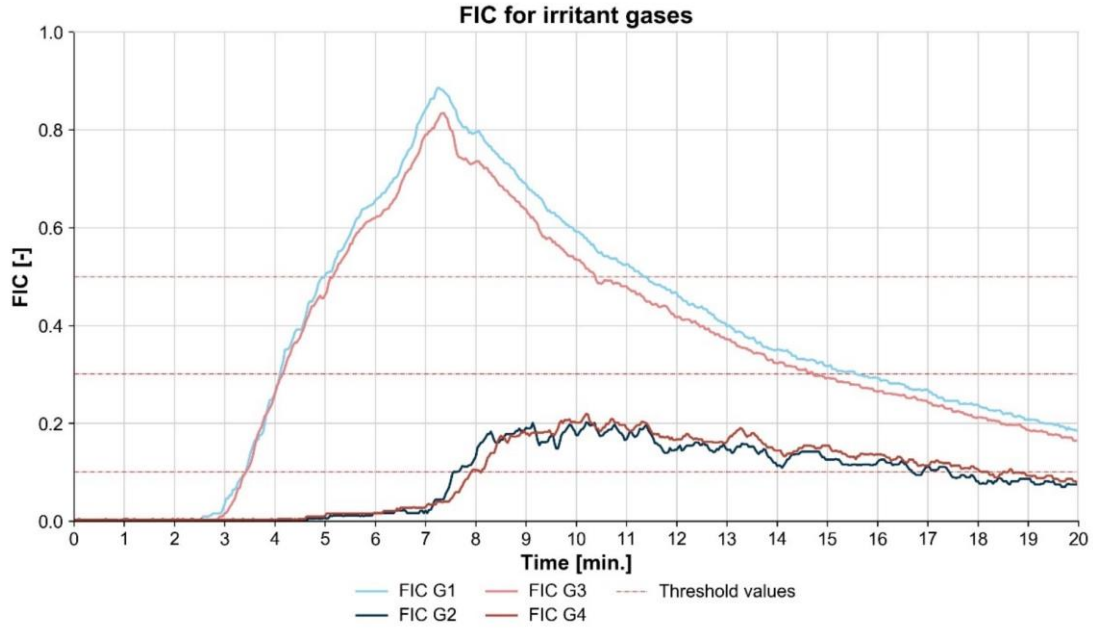
FED for heat



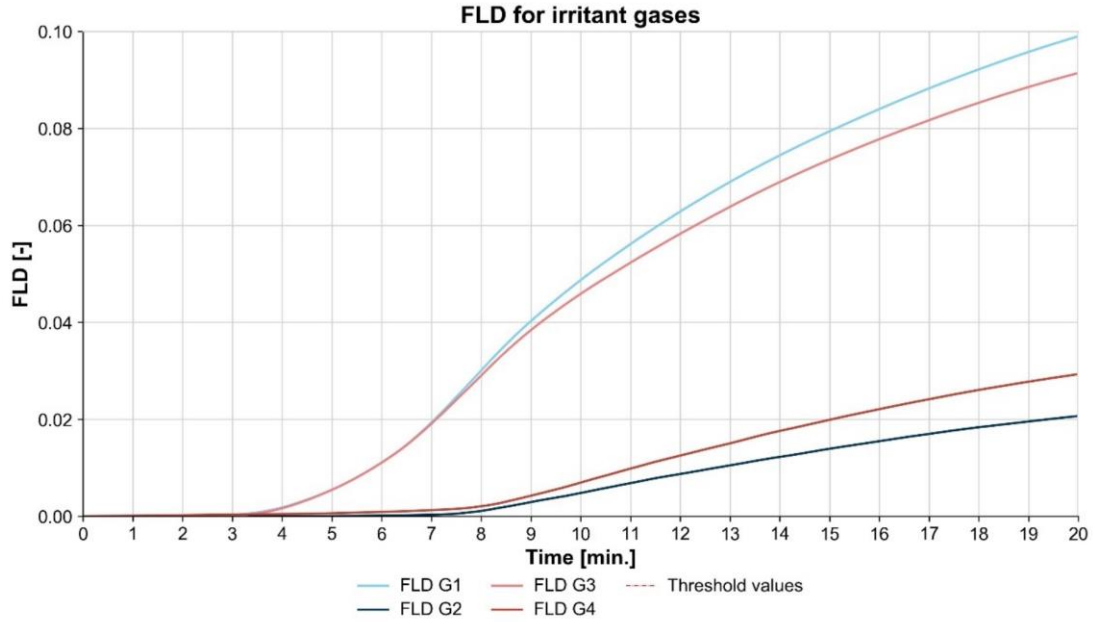
FED for asphyxiant gases



FIC for irritant gases

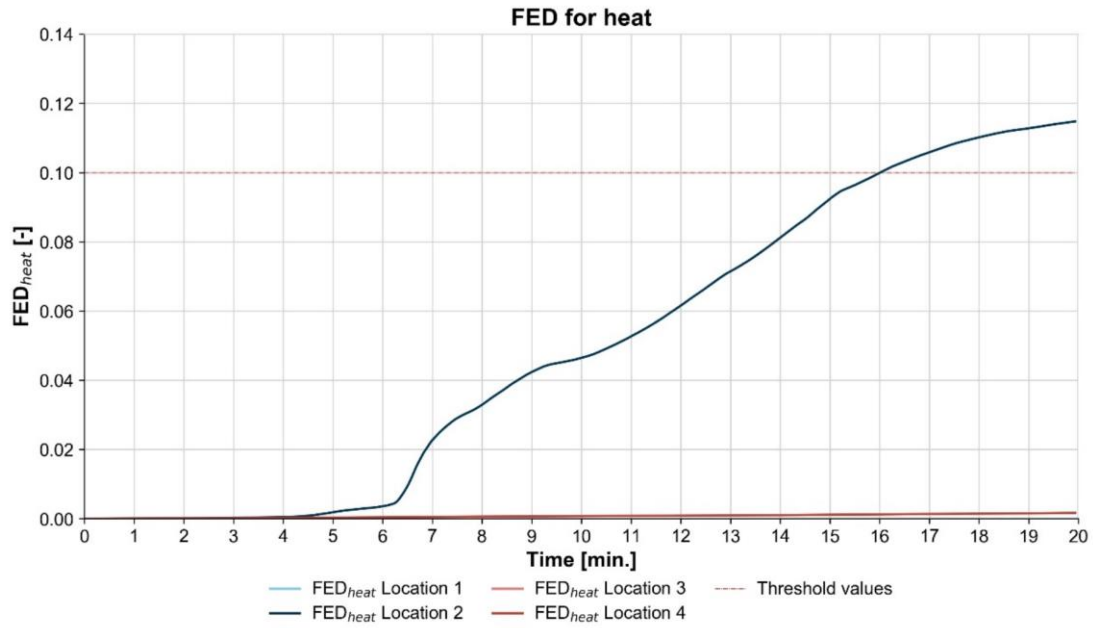


FLD for irritant gases

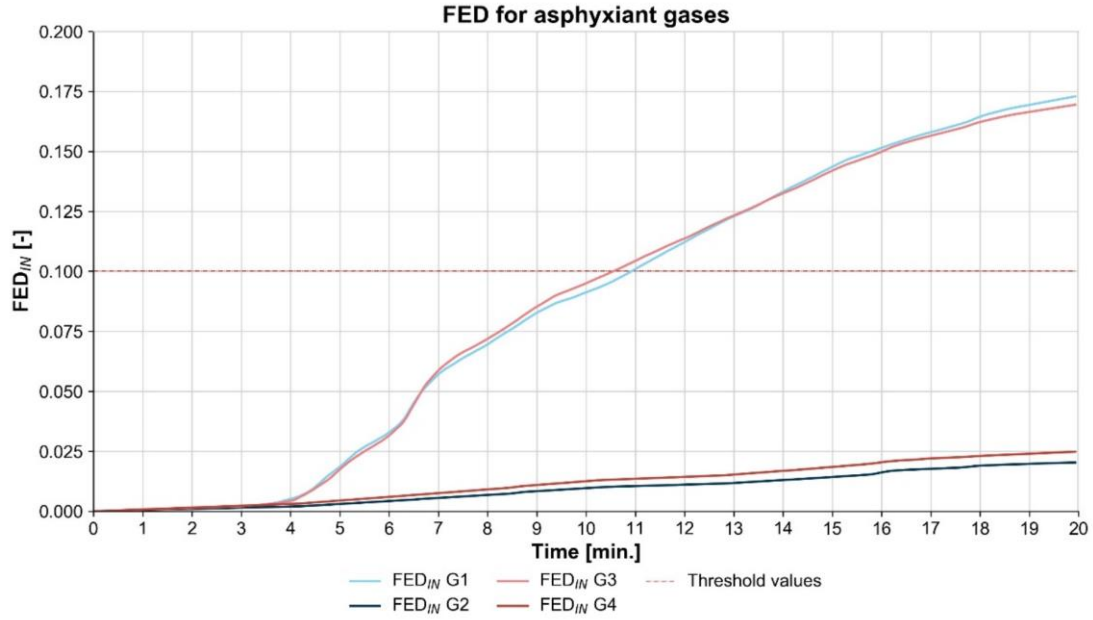


Test 4 conventional chair (door open)

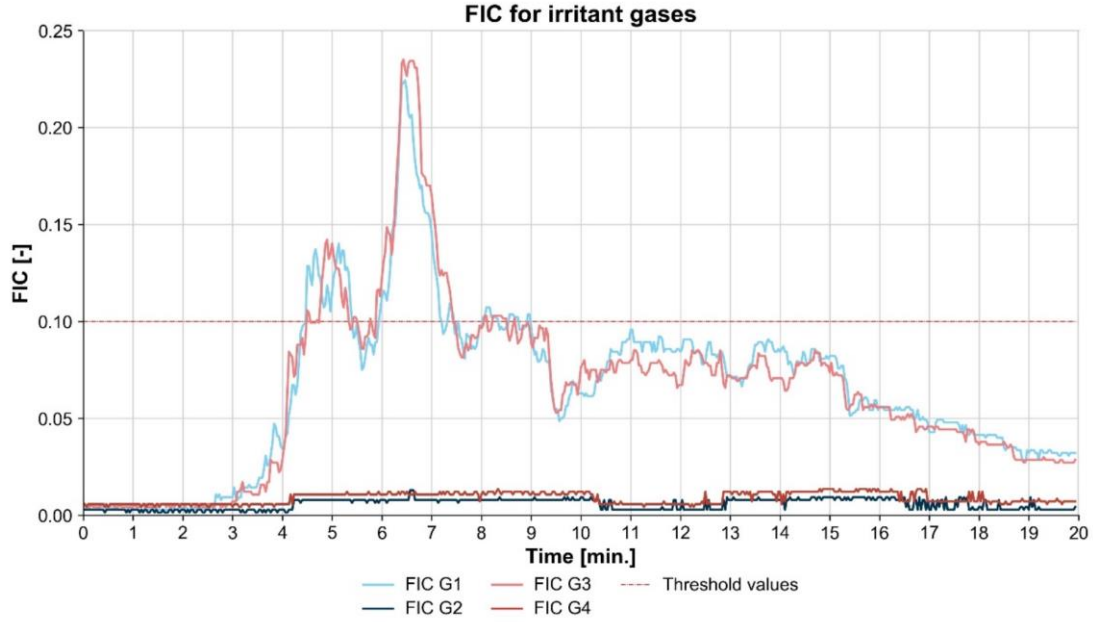
FED for heat



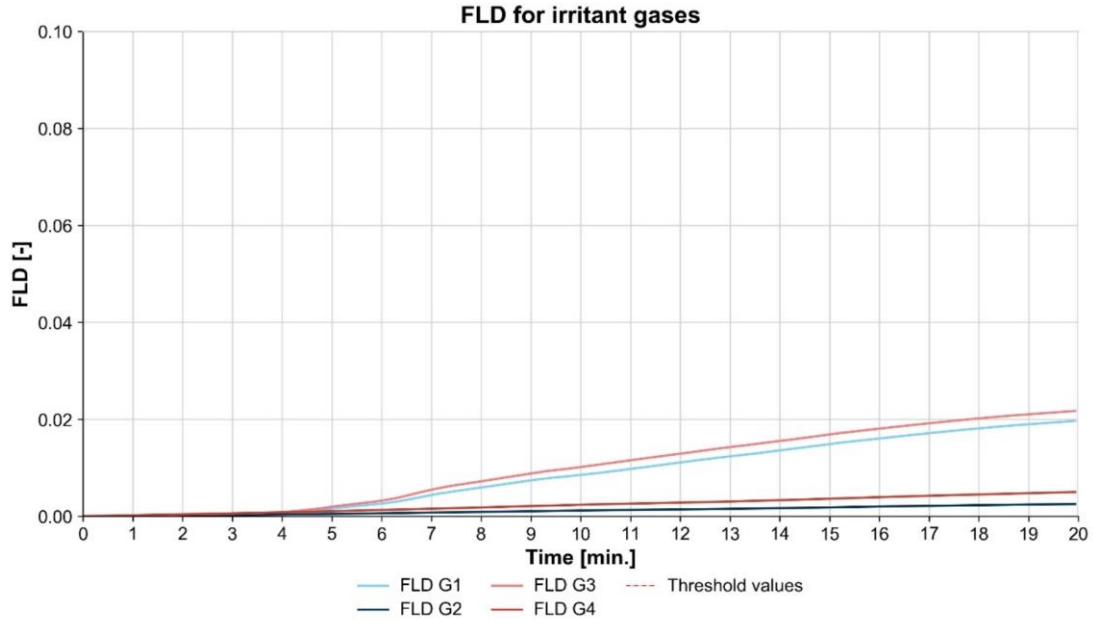
FED for asphyxiant gases



FIC for irritant gases



FLD for irritant gases



Appendix 3 Images of the tests

Test 1 new chair door closed (12 minutes, 1 image every minute starting at t = 1 minute)


2021/04/08 09:18:20
2021/04/08 09:19:20
2021/04/08 09:20:20
2021/04/08 09:21:20
2021/04/08 09:22:20
2021/04/08 09:23:20

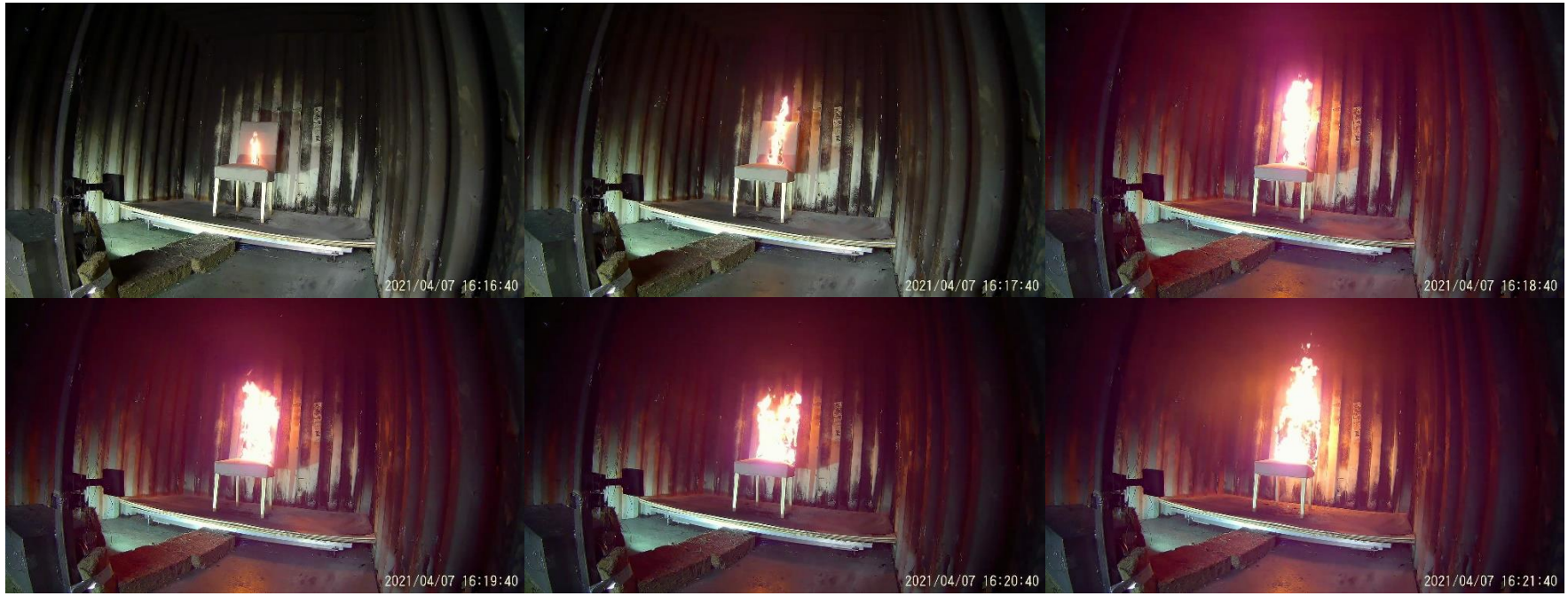
Test 2 new chair door open (12 minutes, 1 image every minute starting at t = 1 minute)


2021/04/07 13:09:24
2021/04/07 13:10:24
2021/04/07 13:11:24
2021/04/07 13:12:24
2021/04/07 13:13:24
2021/04/07 13:14:24

Test 3 conventional chair door closed (12 minutes, 1 image every minute starting at t = 1 minute)


2021/04/07 14:35:10
2021/04/07 14:36:10
2021/04/07 14:37:10
2021/04/07 14:38:10
2021/04/07 14:39:10
2021/04/07 14:40:10

Test 4 conventional chair door open (12 minutes, 1 image every minute starting at t = 1 minute)




2021/04/07 16:22:40
2021/04/07 16:23:40
2021/04/07 16:24:40
2021/04/07 16:25:40
2021/04/07 16:26:40
2021/04/07 16:27:40