BRANDWEER
Brandweeracademie

Impression tests mattresses

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 mattresses*. Arnhem: Institute For Safety.

Commissioned by:	Royal Auping B.V.
Contact:	G. Doorlag
Title:	Impression tests mattresses
Date:	July 6, 2021
Status:	Final
Version:	1.0
Author:	L. Wolfs BBA, ing. R.M.M. van Liempd, 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

Content

Samenvatting

Elk jaar overlijden in Nederland ongeveer 30 en in Europa ongeveer 5000 mensen bij woningbranden. Meer dan een derde van deze fatale woningbranden begint in bekleed meubilair of een matras. Het aantal doden bij woningbranden kan daardoor fors dalen wanneer het brandgedrag van bekleed meubilair en matrassen verbeterd wordt.

Koninklijke Auping B.V. heeft een nieuw matras ontwikkeld dat is samengesteld uit andere materialen. Dit matras is ontwikkeld vanuit het oogpunt van duurzaamheid en circulariteit, maar het heeft ook een verwacht positief effect op het brandgedrag van het matras. Om het verschil in brandgedrag te bepalen heeft Koninklijke Auping B.V. aan de Brandweeracademie van het IFV gevraagd om impressietesten te doen van de nieuwe en conventionele matrassen. Tijdens deze impressietesten staan de volgende onderzoeksvragen centraal:

Onderzoeksvraag 1:
Wat is het brandgedrag in een slaapkameromgeving van nieuwe en conventionele matrassen van Auping als deze worden blootgesteld aan gebruikelijke ontstekingsbronnen zoals een sigaret en een crib 5?

Onderzoeksvraag 2:
Wat is het effect op de vluchtveiligheid en overleefbaarheid in de slaapkameromgeving bij een brand in de nieuwe en conventionele matrassen van Auping?

Om deze onderzoeksvragen te beantwoorden zijn vier testen gedaan. Met zowel het conventionele als het nieuwe matras is één test met de deur van de ruimte open en één test met de deur van de ruimte gesloten uitgevoerd. Tijdens de testen zijn temperatuur, straling, massa-afname, koolstofmonoxide (CO), koolstofdioxide (CO_2), zuurstof (O_2) en stikstofoxiden (NO_x) gemeten. Op basis van deze metingen worden het brandgedrag en de vlucht- en overlevingsmogelijkheden bepaald.

In de testen is vastgesteld dat zowel het conventionele als het nieuwe matras niet wordt ontstoken door een sigaret. Het brandgedrag bij een ontsteking met crib 5 verschilt sterk bij het nieuwe en conventionele matras. Het nieuwe matras draagt niet echt bij aan de verbranding. Op het moment dat de crib 5 is opgebrand dooft de brand bij het nieuwe matras. Zelfs bij een grotere ontstekingsbron (100 ml brandbare vloeistof) dooft de brand wanneer de vloeistof is opgebrand. Het conventionele matras daarentegen brandt fel en intens. Binnen 10 tot 17 minuten is het matras nagenoeg volledig weggebrand (deur open en deur dicht). Het conventionele matras produceert voldoende warmte om andere brandbare objecten in de kamer tot ontbranding te brengen (vooral bij de test met deur open).

Dit verschil in brandgedrag is ook terug te zien in het verschil in vlucht- en overlevings-mogelijkheden. Met enkel het nieuwe matras dat betrokken is bij een brand, heeft een persoon een oneindig lange tijd waarin hij kan vluchten en overleven. Bij het conventionele matras dat brandt, is er een belemmerde ontvluchting na 3 - 8 minuten, een levens-bedreigende situatie na 4 - 9 minuten en een fatale situatie na 5 - 12 minuten (afhankelijk van de doelgroep, meethoogte en de stand van de deur). Slechts één conventioneel matras dat brandt, is voldoende om een fatale situatie te verzoorzaken in een kamer van 14 m^2.

Introduction

Background

Every year, about 30 people in the Netherlands and about 5000 people in the EU die as a result of a residential fire. Statistics show that at least 36% of fires in dwellngs started in upholstered furniture and mattresses (Annual overview of fatal residential fires 2020, 2021). International research shows comparable figures. The number of deaths and injuries can drop significantly if the fire safety of upholstered furniture and mattresses is improved.
So for the past ten years, the Fire Service Academy of the Institute for Safety has had the mission to improve the fire safety of upholstered furniture and mattresses in the residential environment. In 2016, the Fire Service Academy carried out a study commisioned by the FEU (Federation of European Union Fire Officer Associations) to explore what kind of tests are necessary to make upholstered furniture and mattresses more fireproof. In the 2017 report (Fire safety of upholstered furniture and mattresses in the domestic area), the FEU advises manufacturers and governments on what test methods should be used for upholstered furniture and mattresses. The FEU report also refers to another study on impression tests with upholstered furniture and mattresses (Impression tests upholstered furniture and mattresses, 2017). In this study, the most sold sofas and mattresses were tested for ignition and fire behavior in a realistic residential environment.

Following an article on fireproof furniture, Royal Auping B.V. contacted the Fire Service Academy. Royal Auping B.V. has developed a mattress (Auping Evolve) in which a different material composition is used than in conventional mattresses. These different materials have an intended circular economy benefit and a presumed fire safety benefit. Royal Auping B.V. has asked the Fire Service Academy to perform impression tests with their new and conventional mattresses.

Purpose and research questions

The purpose of this research is to get an impression of the fire behaviour of the newly developed mattress of Royal Auping B.V. and the possibility 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 mattresses. This involves testing the fire behavior in a realistic environment. So it is not about laboratory tests but about impression tests in a residential environment.
On the basis of these objectives the following research questions are defined.

Research question 1:
What is the fire behaviour in a bedroom environment of the new and conventional mattresses of Royal Auping B.V. when exposed to common test ignition sources such as a cigarette and crib 5?

Research question 2:
What is the possibility of escape and survivability in a bedroom environment when only the new or conventional mattress of Royal Auping B.V. is burning?

Scope

As mentioned above the purpose is to get an impression of the fire behaviour, possibility of escape and survivability in a bedroom environment. In order to get a good impression a limited number of fire tests (experiments) have been carried out.
In addition to this, it should be stated that there is no such thing as a standard bedroom or representative fire scenario. That is why the tests are carried out in a room that resembles a bedroom and a fire scenario that is common in practice. This means that this is a descriptive study to get an impression and does not have the intention to provide a comprehensive description of the fire behaviour, possibility of escape and survivability in the residential environment.

1 Research method

1.1 Practical research

This section describes the experimental design of the practical research. The research method consists of the mentioned experiments. Because the purpose is to get an impression of the fire behaviour of the mattresses of Royal Auping B.V. only four experiments were carried out.

1.2 Experimental design

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

1.2.1 General description

The experiments took place on April 7, 2021. The experiments were carried out on a fire training area (Troned Twente Safety Campus, the Netherlands). In this area a 20 feet ISO container is located, which 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 figure 1.2.

Figure 1.1 Floor plan

Figure 1.2 Exterior view of the container

1.2.2 Objects

To get an impression of the fire behaviour of mattresses of Royal Auping B.V. the newly developed mattress and the conventional mattress were tested.

The conventional mattress is a pocket sprung mattress which contains steel, polyester textiles and PU foams. The new mattress is also a pocket sprung mattress. This mattress is made of steel and polyester and contains no foam or latex. Both mattresses are presented in figure 1.3. The cross-section and material composition of both mattresses can be found in Appendix 1.

Figure 1.3 The conventional mattress on the left and the new mattress (Auping Evolve) on the right

1.2.3 Ignition sources and protocol

There are well known test methods, standards and ignition sources for testing upholstered furniture and mattresses. During the impression tests, a modified test protocol was used. In the protocol, the generally known test methods and standards have not been followed exactly. However, the prescribed ignition sources from the generally known test methods were used during the tests. One ignition source is not found in tests methods. A ignition with 100 ml isopropanol was added as an ignition source, because small scale tests indicated that a fire in the new mattress would die out with a crib 5 test. There fore an extra large igniton source was added. This ignition source represents a burning object on the mattress (e.g. a blanket).

The following ignition sources were used:

> Test cigarettes (SRM 1196);

> Larger ignition source (crib 5);
> Extra large ignition source (100 ml isopropanol).

The following protocol per ignition source was used:

> Cigarette:
  - If, after 5 minutes after burning the cigarette, no flames were visible, the test was aborted.
  - If flames were visible within start test to 5 minutes after burning the cigarette, the test was completed. The test was terminated when the object was (largely) burned.

> Crib 5:
  - Object is ignited by crib 5 as an ignition source. When no flames were visible after the crib 5 was burned away, the test was aborted.
  - If flames were visible after burning the crib 5, the test was terminated when the object was (largely) burned.

> Isopropanol:
  - 100 ml of isopropanol was used as an ignition fluid to ignite the object. When no flames were visible anymore, the test was aborted.
  - If flames were visible, the test was terminated when the object was (largely) burned.

In table 1.2 a summary of the fire tests is presented.

Table 1.2 Fire tests

Object	Test	Ignition source	Test no.
New mattress 1	- Door closed Door closed	Cigarette Crib 5 100 ml isopropanol	- 1a 1b
New mattress 2	- Door open Door open	Cigarette Crib 5 100 ml isopropanol	- 2a 2b
Conventional mattress 1	- Door closed	Cigarette Crib 5	- 3
Conventional mattress 2	- Door open	Cigarette Crib 5	- 4

1.2.4 Measurements and measurement protocol

During the experiments temperature, radiation heat flux, mass loss, carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O2) and nitrogen oxides (NOx) were measured. The measurements were started when the object is 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 O2) were measured at two positions, on two levels (0.5 and 1.5 meters). Radiation heat flux was measured at one positions on two levels (0.5 and 1.5 meters) and in two directions (facing the ceiling and facing the fire).

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 from the floor. Both were directed to the fire source. In addition, two action cameras were used to record the fire behaviour and smoke propagation. One camera was placed on the floor in the doorway and another camera 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 a steel bed frame on top of the plasterboard.

The details about the measurements, tools and position are included in table 1.3 and figure 1.4. More detailed information about the measuring equipment, its technical specifications and the possibility of measurement errors is given in the report smoke propagation in residential buildings (Fire Service Academy, 2020, para. 2.4.5).

Table 1.3 Details 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	Thermocouple tree 1	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
Oxygen (O2)	Testo's	Every 2 seconds	2 positions	2 levels 0.5 and 1.5m
Nitrogen Oxides (NOx)	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 1.4 and figure 1.5. 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 walll 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.

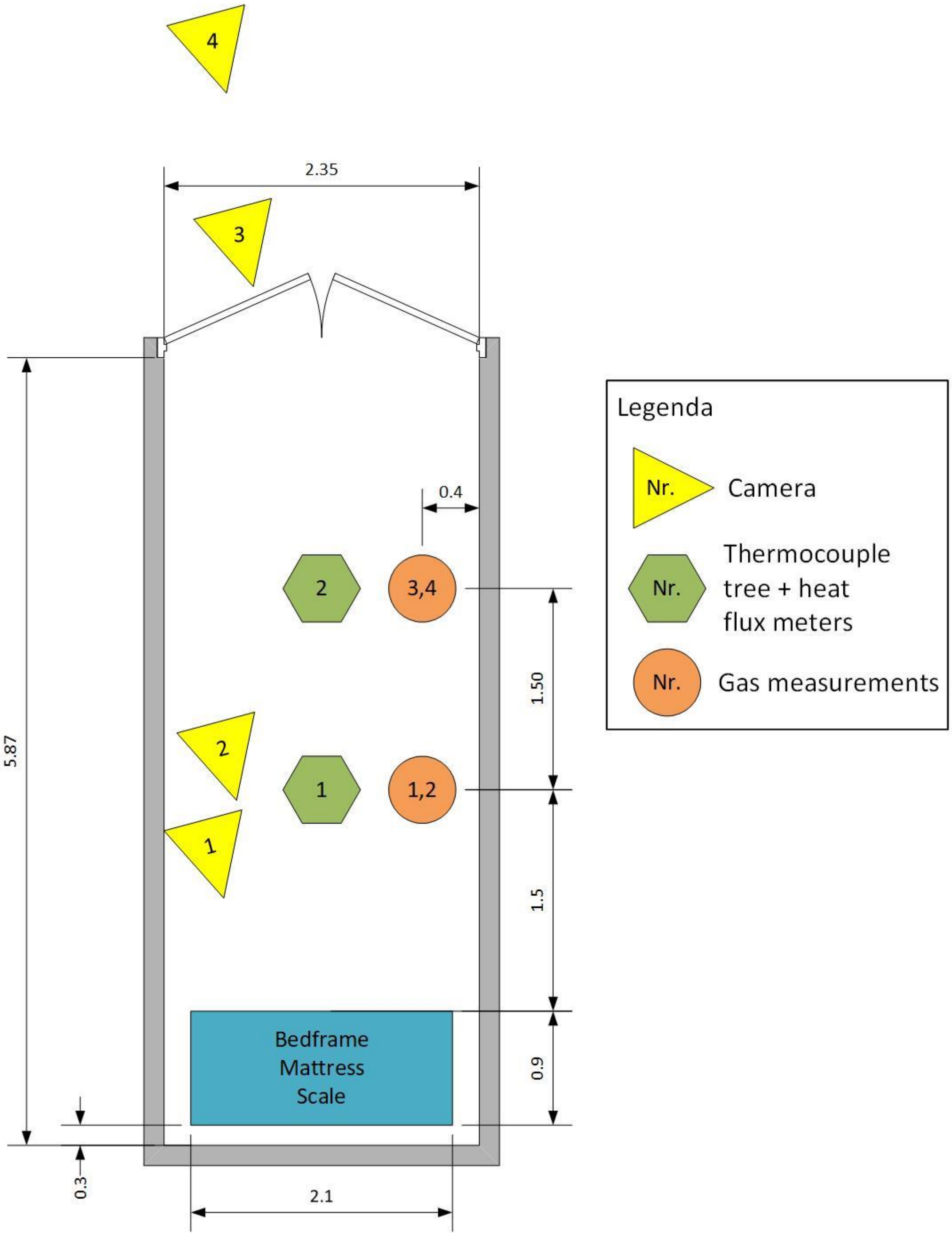


Figure 1.4 Measurement tools and location on the floor plan

Figure 1.5 Test set up

1.2.5 Test protocol

Cigarette test

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

The test protocol of the cigarette tests was as followed:

> Ignite cigarette and supply air to the cigarette until a minimum of 5 and a maximum of 8 mm of the cigarette has been incinerated.
> Place the cigarette on the mattress.
> Wait for flames to develop or a progressive smoldering fire.
> If this has not happened within an hour, this is considered as ‘mattress not ignited’.
> If the cigarette is burned out or extinguished and nothing is visible on the mattress, this also is considered as ‘mattress not ignited’.
> If flames develop, extinguish 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 top of the mattress and ignited. One door to the fire room was left completely open for the first minute of the test to observe the progress. After one minute, the door is

placed in the correct position for the rest of the test. During two tests, one with the new mattress and one with the conventional mattress, the door remained completely open. During the other two tests the door was closed after one minute.
The closed door is not in the lock, but is held against the closing hook of the container door with a block of concrete. That way there is a small gap, which can be seen as a leakage that every room has.

Isopropanol test
In case the fire extinguishes with a crib 5 as an ignition source, a test with an extra large ignition source was done. This test provides insight into how the mattress would behave under the influence of a fire in another object near the mattress or in the case of arson with a flammable liquid.

In this case, an ignition source with a flammable liquid has been chosen. Another fire object near the mattress has not been chosen, because the gasses coming from this burning object will probably influence the measurement of the gasses released from the mattress.

In the extra heavy test, 100 ml isopropanol is used as an ignition fluid. A layer thickness of 5 mm gives a surface of 200 cm^2 on the mattress. This corresponds to a circle with a diameter of 16 cm. The 100 ml of isopropanol is gently applied to the mattress. After 1 - 2 minutes the liquid is ignited. Also during the tests with isopropanol, one door to the fire room was left completely open for the first minute of the test to observe the progress. After one minute, the door is placed in the correct position for the rest of the test.

1.3 Data analysis

1.3.1 Limit values for ignition

After the experiments the visible data is analyzed with the limit values for ignition. The used limit values are practical limits which are not the same as limit values from commonly known test methods. However these limits give an impression about the ignitability of the objects. The following limit values are used:

> Cigarette test: no flames visible from start test until 5 minutes after the cigarette is completely burned;
> Crib 5 test: no flames visible after burning the crib.

1.3.2 Threshold values for the possibility of escape and survivability

After the experiments the measured data is 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 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, para. 2.5.2).

The possibility of escape and survivability for people who are present until the moment they escape or are rescued is determinative in preventing fire casualties. This is because it is important in a fire situation that the available safe escape time (ASET) is longer than the required safe escape time (RSET). The conditions to which people are exposed in the rooms in question, and their vulnerability for 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 1.6).

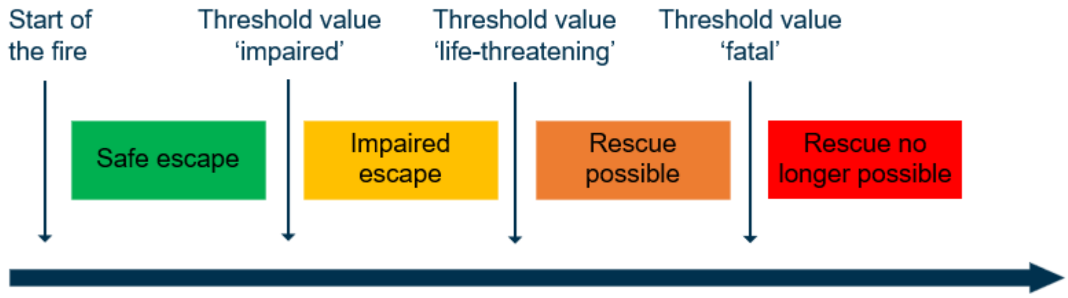


Figure 1.6 Diagram of the possibility of escape and survivability in the event fire

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 according to the SFPE Handbook can be found in table 1.4.

Table 1.4 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[1]	FEC_{smoke}	0.1	0.3	1.0	-	-	-	-	-	-

[1] In the experiments in this research the visibility is not measured.

2 Results

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

- > Results of the cigarette tests (par. 2.1)
- > Results of the crib no. 5 and isopropanol tests (par. 2.2 for the new mattress and par. 2.3 for the conventional mattress)
- > Comparance of the new and conventional mattress (par. 2.4)

In each paragraph the results are presented and afterwards an analysis of the results if given. The results are presented as follows:

- > Cigarette tests
  - – Photo’s of the tests
- > Results of the crib no. 5 and isopropanol tests
  - – Photo’s of the 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 each group at a height of 0,5 and 1,5 m
- > Comparance of the new and conventional mattress
  - – Stacked bars with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) for each 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 **Fout! Verwijzingsbron niet gevonden.**)

(green)	Safe escape
(yellow)	Impaired escape
(orange)	Life-threatening situation
(red)	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 of the results in this chapter are a summary of the full results and an extensive analysis. The following appendixes provide the basis for the results and analysis in this chapter:

- > Appendix 2: graphs of all the measured values during the tests for each test.
- > Appendix 3: 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.

2.1 Cigarette tests

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

2.1.1 Cigarette test new mattresses

Figure 2.2 and figure 2.3 show images of the cigarette tests with the new mattresses.

Figure 2.2 Cigarette test 1 new mattress

Figure 2.3 Cigarette test 2 new mattress

Analysis

The photos show that the mattress is not ignited by a burning cigarette. After the cigarette is extinguished no smouldering appears in the filling or in the top layer of the mattress. Only the top layer is slightly melted away due to the burning cigarette. The object has passed the cigarette test.

2.1.2 Cigarette test conventional mattresses

Figure 2.4 and figure 2.5 show images of the cigarette tests with the conventional mattresses.

Figure 2.4 Cigarette test 1 conventional mattress

Figure 2.5 Cigarette test 2 conventional mattress

Analysis
The photos show that the mattress is not ignited by a burning cigarette. After the cigarette is extinguished no smouldering appears in the filling or in the top layer of the mattress. Only the top layer is slightly charred due to the burning cigarette. The object has passed the cigarette test.

2.2 Fire tests new mattresses

In this section the results of the crib 5 tests and isopropanol tests for the new mattress are presented.

2.2.1 Crib 5 test new mattress door closed (test 1a)

Below the results for test 1a are presented with:
> Photo’s of the test (see figure 2.6 till figure 2.8)
> Graphs of measured values during the test (see figure 2.9 till figure 2.11)
> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.1)

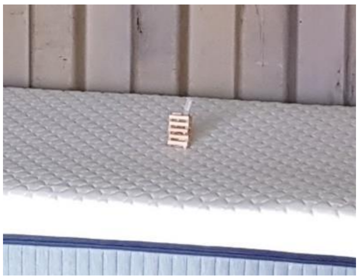


Figure 2.6 Crib 5 on the mattress before the test

Figure 2.7 Maximum fire size during the test

Figure 2.8 Mattress after the test

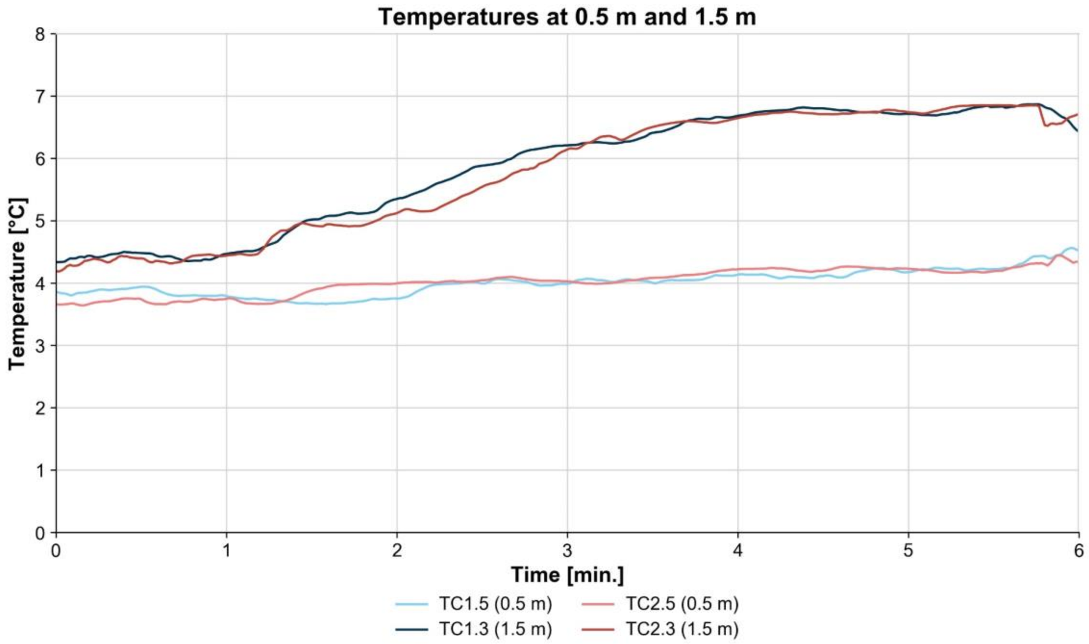


Figure 2.9 Temperatures at 0.5 and 1.5 m height [°C] for test 1a

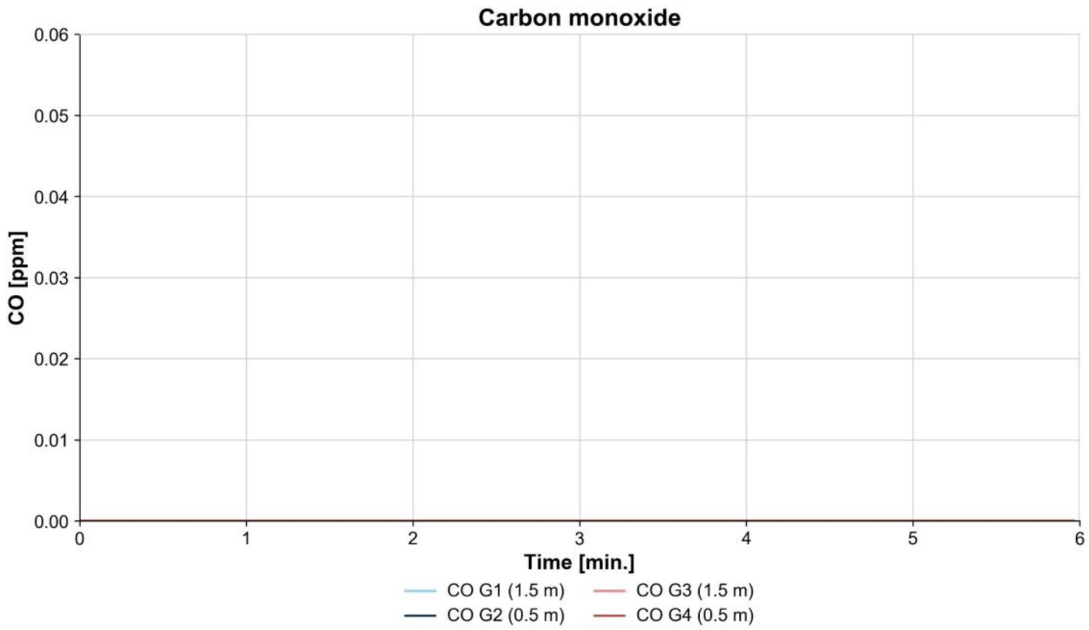


Figure 2.10 Carbon monoxide concentration at 4 locations [ppm] for test 1a

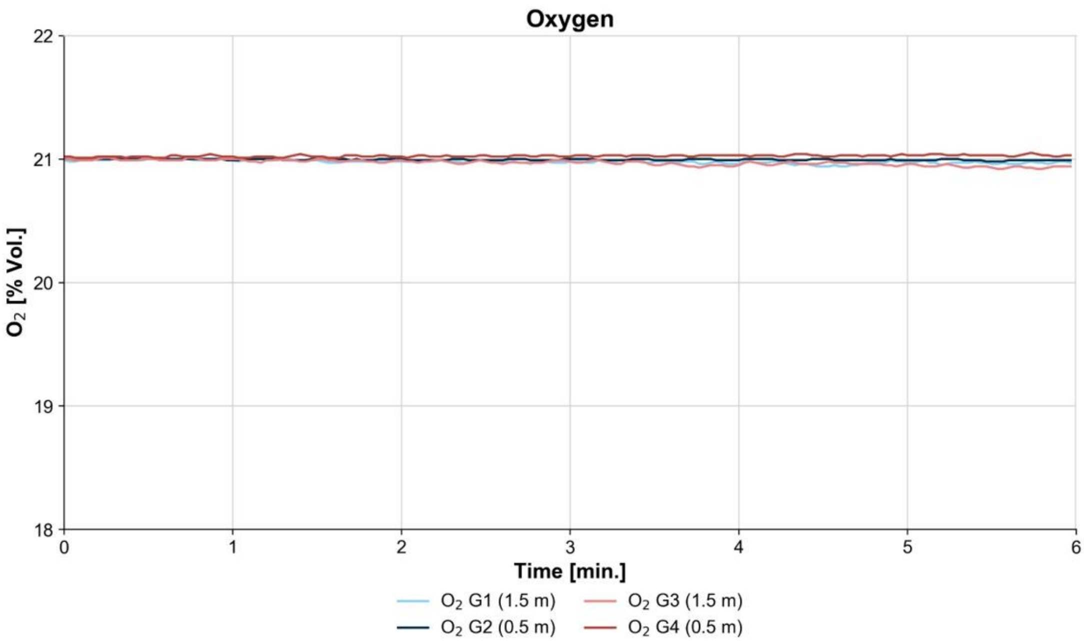


Figure 2.11 Oxygen concentration at 4 locations [% vol.] for test 1a

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

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

During the test, the maximum temperature rise was less than 10 °C. No carbon monoxide was measured. After the crib 5 was burned completely the fire died out. Only a small part of the mattress, nearby the location of the crib 5 was burned away after the test. The mattress did not seem to contribute to the fire. This resulted in a possibility of safe escape for the complete duration of the test.

2.2.2 Isopropanol test new mattress door closed ((test 1b)

Below the results for test 1b are presented with:

- Photo’s of the test (see figure 2.12 and figure 2.13)
- Graphs of measured values during the test (see figure 2.14 till figure 2.16)
- Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.2)

Figure 2.12 Maximum fire size during the test

Figure 2.13 Mattress after the test

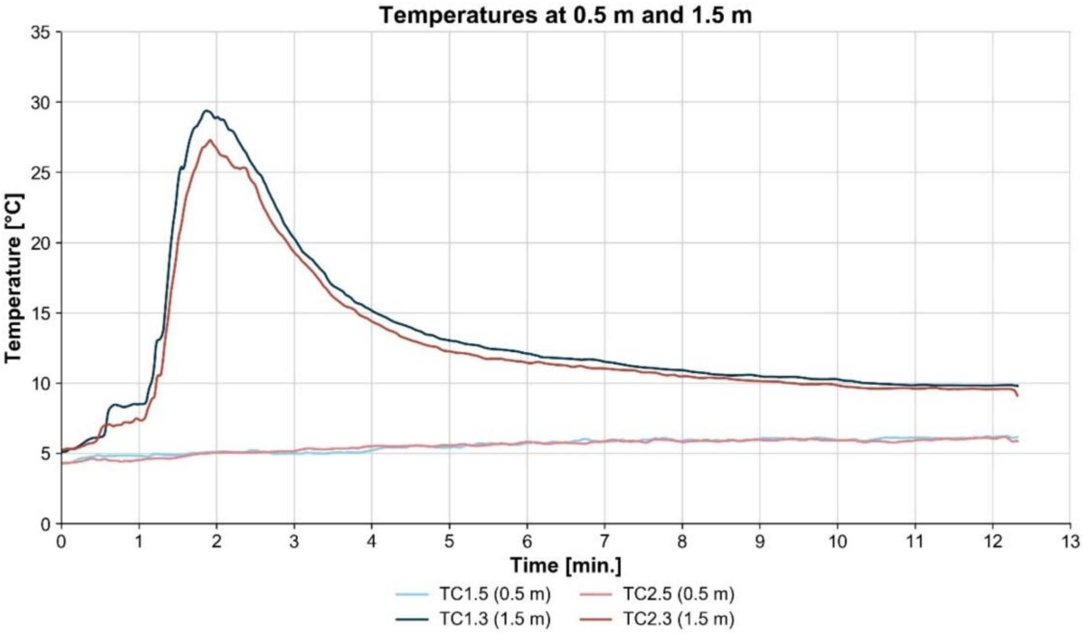


Figure 2.14 Temperatures at 0.5 and 1.5 m height [°C] for test 1b

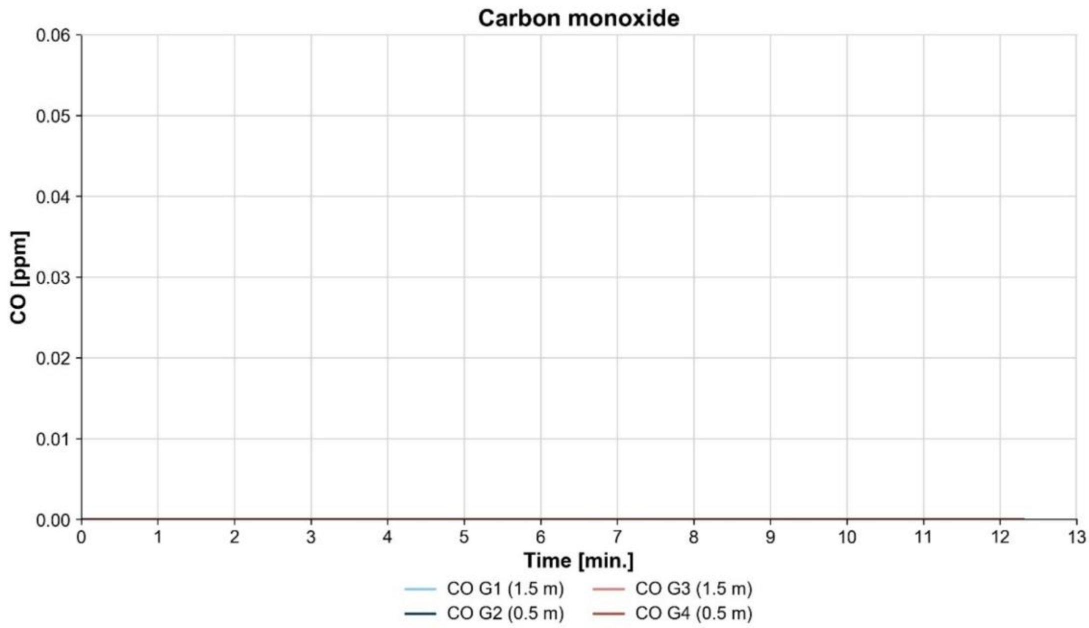


Figure 2.15 Carbon monoxide concentration at 4 locations [ppm] for test 1b

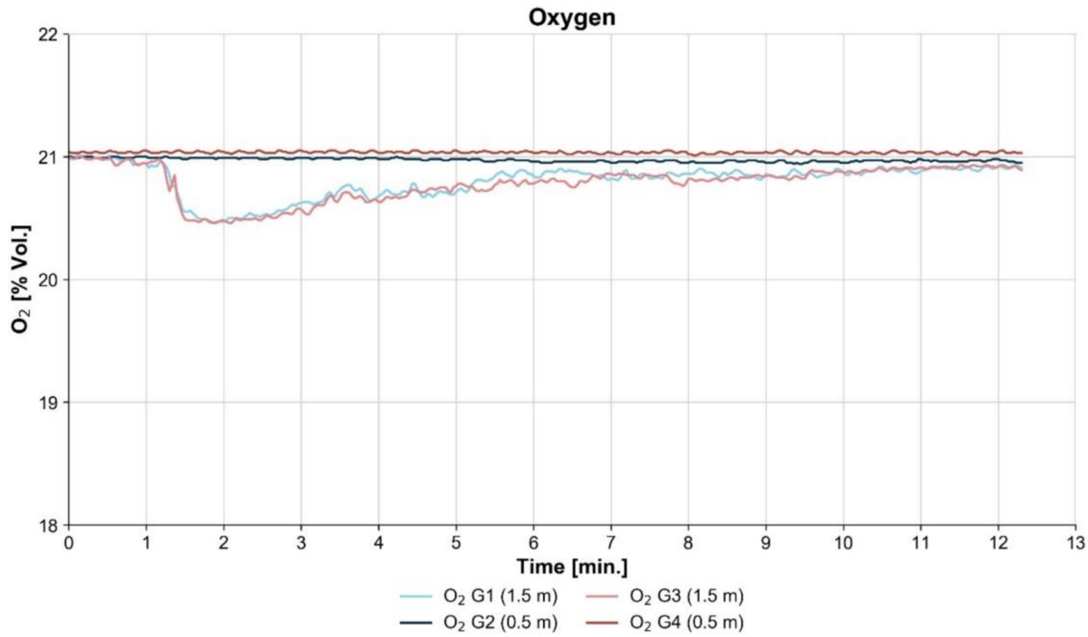


Figure 2.16 Oxygen concentration at 4 locations [% vol.] for test 1b

Table 2.2 Times for the possibility of escape and survivability (in minutes) for test 1b

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
During the test, the maximum temperature rise was about 50 °C. No carbon monoxide was measured. It seemed that the fire died out after the isopropanol was burned away. Only a small part of the mattress, where the isopropanol was applied to the mattress, was burned away after the test. The mattress did not seem to contribute to the fire. This resulted in a possibility of safe escape for the complete duration of the test.

If the mattress doesn't really contribute to the fire with 100 ml of flammable liquid as the ignition source, it will most probably also not really contribute to the fire if a blanket on top of the mattress is burning. What the burning behaviour of the matrress is in a fully developed room fire has not been tested and is unknown at this point.

2.2.3 Crib 5 test new mattress door open (test 2a)

Below the results for test 2a are presented with:
> Photo's of the test (see figure 2.17 till figure 2.19)
> Graphs of measured values during the test (see

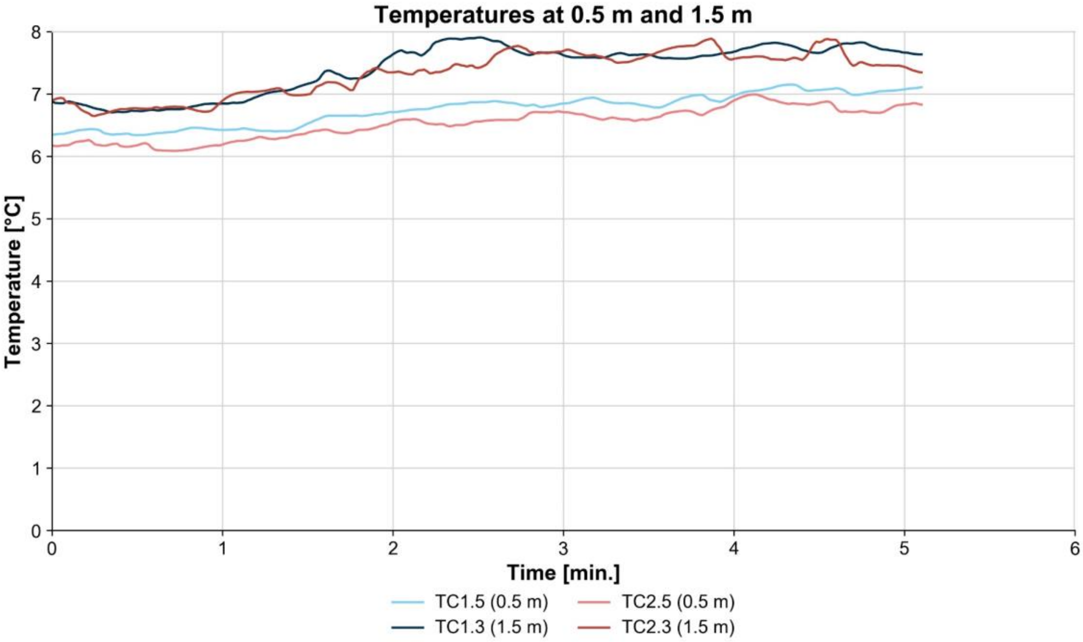


figure 2.20 till figure 2.22)
> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.3)

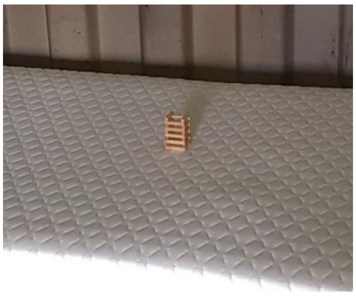


Figure 2.17 Crib 5 on the mattress before the test


Figure 2.18 Maximum fire size during the test

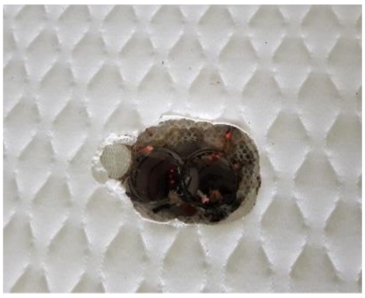


Figure 2.19 Mattress after the test

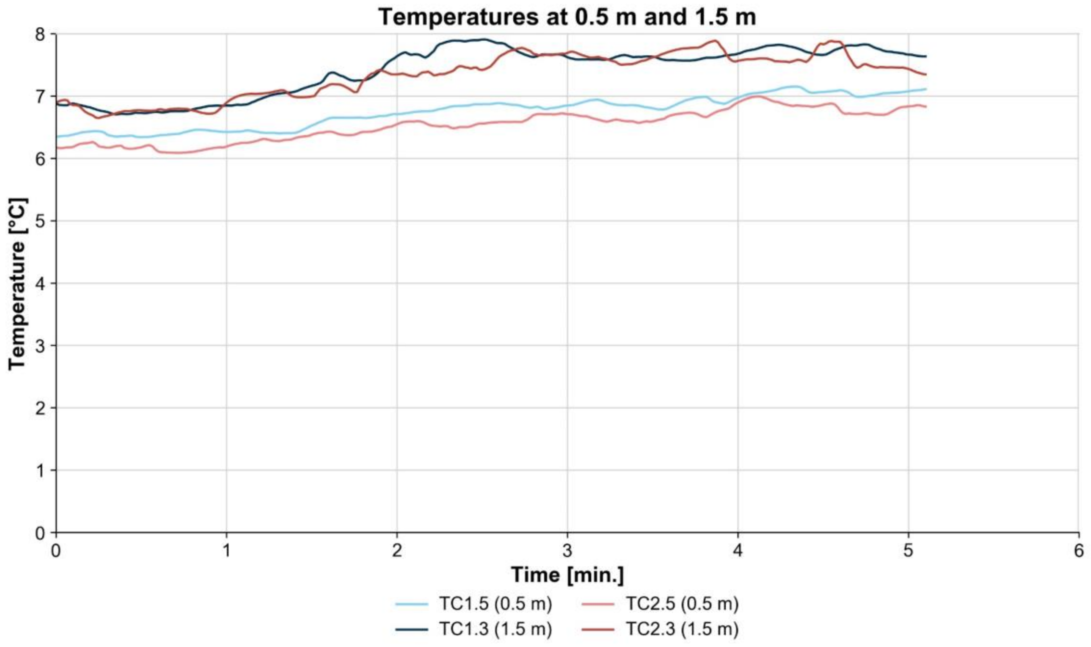


Figure 2.20 Temperatures at 0.5 and 1.5 m height [°C] for test 2a

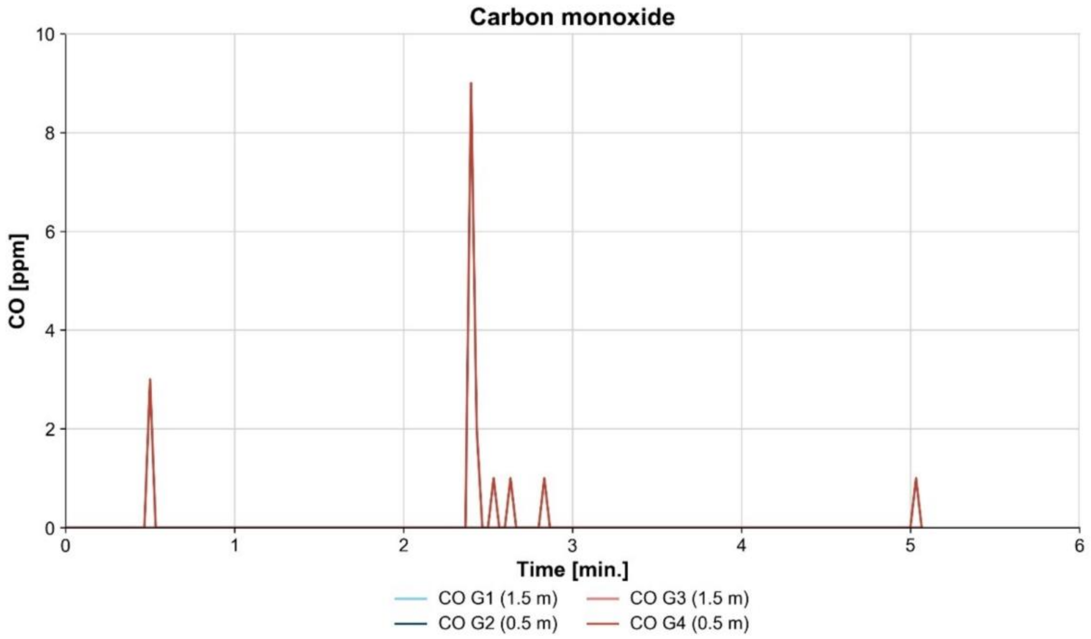


Figure 2.21 Carbon monoxide concentration at 4 locations [ppm] for test 2a

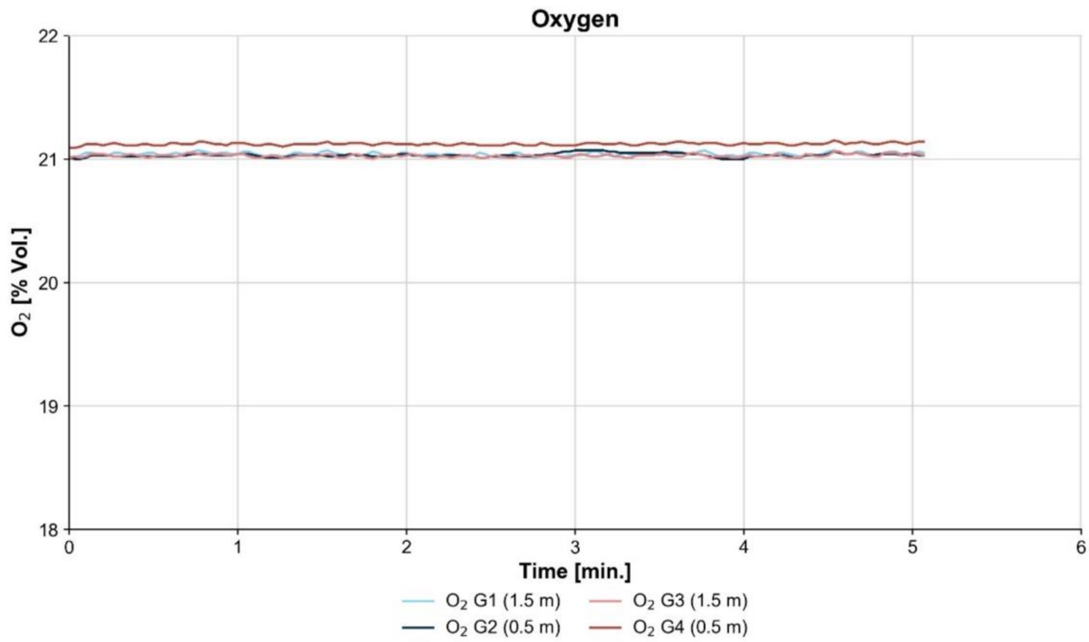


Figure 2.22 Oxygen concentration at 4 locations [% vol.] for test 2a

Table 2.3 Times for the possibility of escape and survivability (in minutes) for test 2a

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

During the test, the maximum temperature rise was less than 10 °C. The maximum carbon monoxide concentration measured was 9 parts per million (ppm). After the crib 5 was burned completely the fire died out. Only a small part of the mattress, nearby the location of the crib 5 was burned away after the test. The mattress did not seem to contribute to the fire. This resulted in a possibility of safe escape for the complete duration of the test.

2.2.4 Isopropanol test new mattress door open (test 2b)

Below the results for test 2b are presented with:

- Photo's of the test (see figure 2.23 and figure 2.24)
- Graphs of measured values during the test (see figure 2.25 till figure 2.27)
- Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.4)

Figure 2.23 Maximum fire size during the test

Figure 2.24 Mattress after the test

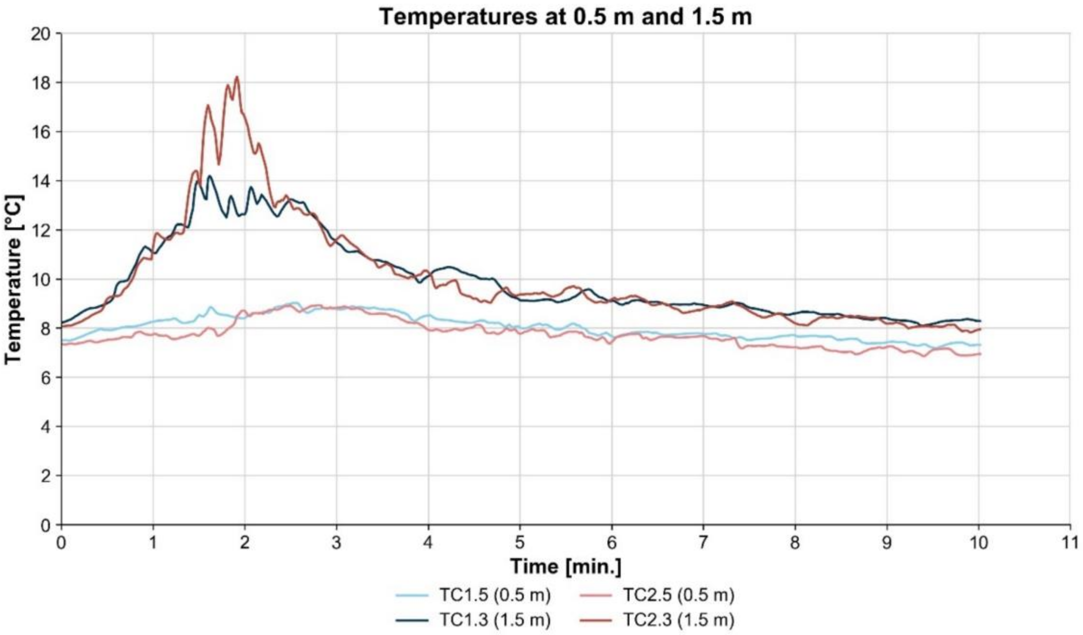


Figure 2.25 Temperatures at 0.5 and 1.5 m height [°C] for test 2b

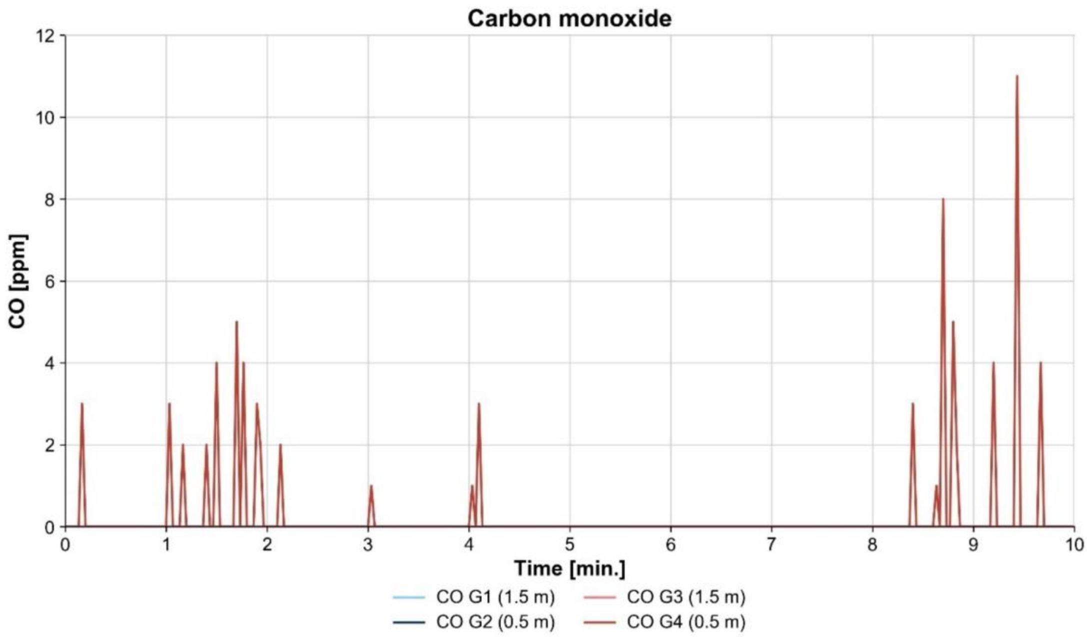


Figure 2.26 Carbon monoxide concentration at 4 locations [ppm] for test 2b

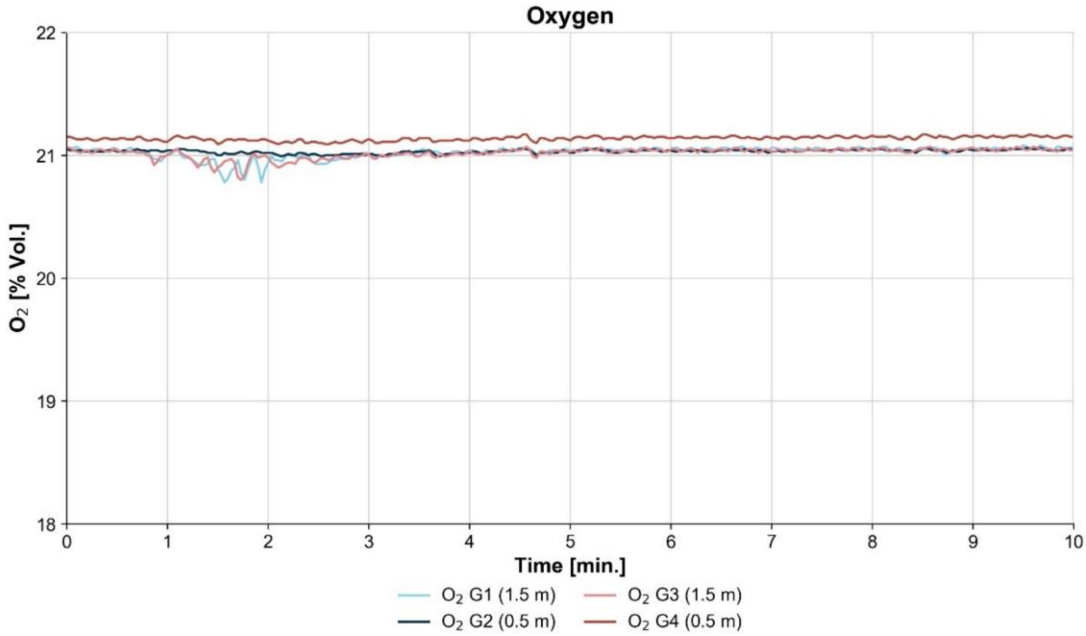


Figure 2.27 Oxygen concentration at 4 locations [% vol.] for test 2b

Table 2.4 Times for the possibility of escape and survivability (in minutes) for test 2b

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
During the test, the maximum temperature rise was about 45 °C. The maximum carbon monoxide concentration measured was 11 parts per million (ppm). It seemed that the fire died out after the isopropanol was burned away. Only a small part of the mattress, where the isopropanol was applied to the mattress, was burned away after the test. The mattress did not seem to contribute to the fire. This resulted in a possibility of safe escape for the complete duration of the test.

If the mattress does not really contribute to the fire with 100 ml of flammable liquid as the ignition source, it will most probably also not really contribute to the fire if a blanket on top of the mattress is burning. What the burning behaviour of the matrress is in a fully developed room fire has not been tested and is unknown at this point.

2.3 Fire tests conventional mattresses

2.3.1 Crib 5 test conventional mattress door closed (test 3)

Below the results for test 3 are presented with:
> Photo's of the test (see figure 2.28 till figure 2.31)
> Graphs of measured values during the test (see figure 2.32 till figure 2.34)
> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.5)


Figure 2.28 Start crib 5 test


Figure 2.29 Fire spreads across the mattress


Figure 2.30 Maximum fire size during the test


Figure 2.31 Mattress after the test

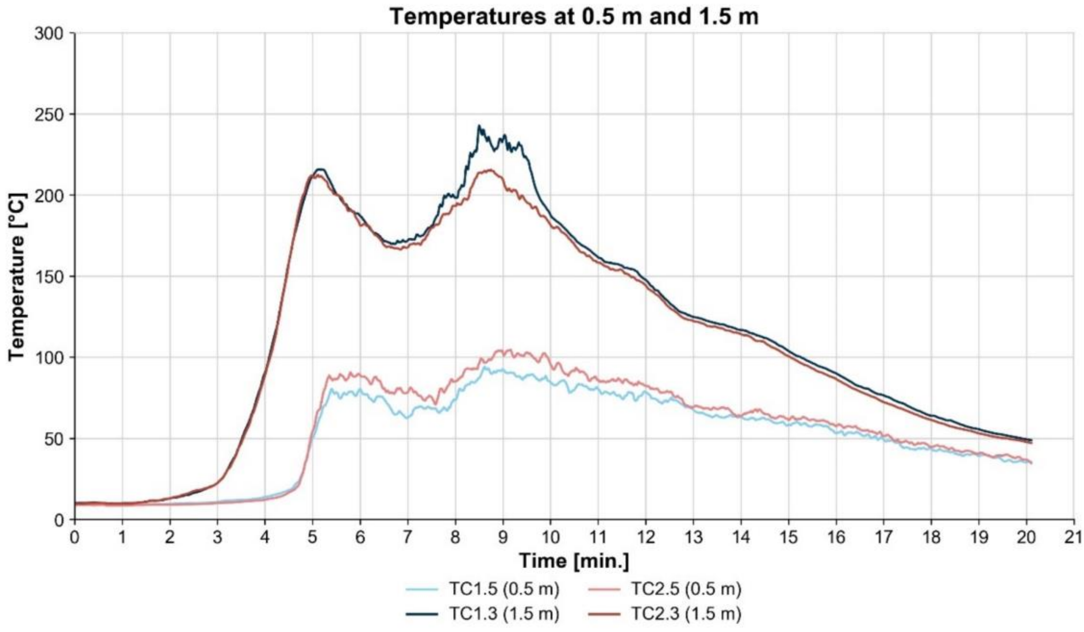


Figure 2.32 Temperatures at 0.5 and 1.5 m height [°C] for test 3

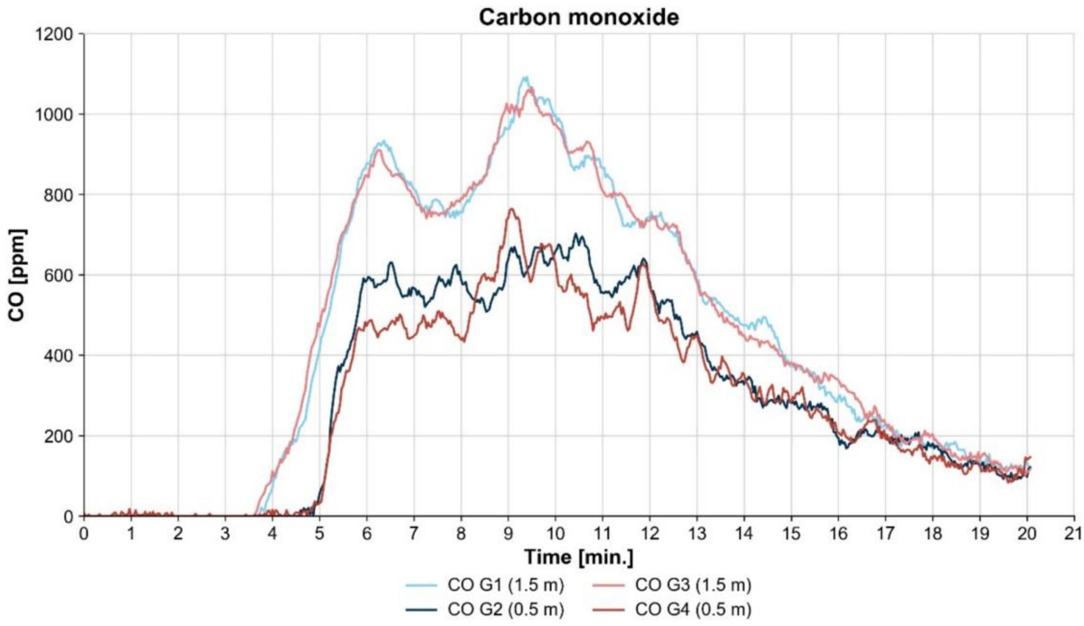


Figure 2.33 Carbon monoxide concentration at 4 locations [ppm] for test 3

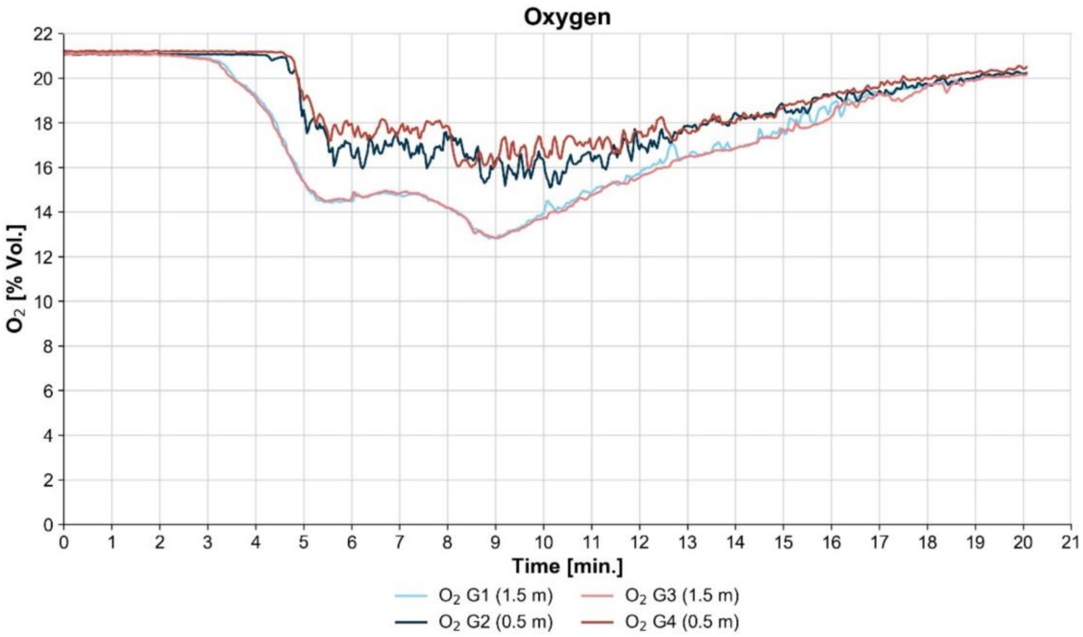


Figure 2.34 Oxygen concentration at 4 locations [% vol.] for test 3

Table 2.5 Times for the possibility of escape and survivability (in minutes) for test 3

Height												
0.5 m	<5	5	5	6	<5	5	7	8	<8	8	9	12
1.5 m	<3	3	4	5	<4	4	5	6	<5	5	7	9

Analysis

During the test, the maximum temperature was about 300 °C after 5 minutes (level 2.2 m). The maximum carbon monoxide concentration measured was about 1100 ppm after 9.5 minutes. The mattress was almost completely burned after the test. This resulted in a life-threatening situation after 4 - 7 minutes at a height of 1.5 meter and 5 - 9 minutes at a height of 0.5 meter (dependent on the vulnerability of the group). A fatal situation occurred after 5 - 9 minutes at a height of 1.5 meter and 6 – 12 minutes at a height of 0.5 meter (dependent on the vulnerability of the group).

The irritant gases are the first to cause an impaired escape for the three groups. Within a few minutes after the irritant gases causes an impaired escape, the heat would also cause an impaired escape. Visibillity wasn't measured but based on video footage the visibility will probably cause an impaired escape within 5 minutes. Visibility will probably be the first to reach the limit value at a height of 0.5 meter for the general group. At the other locations and for the other groups visibility will probably cause an impaired escape at about the same time as the irritant gases.

The irritant and asphyxiant gases are the first to cause a life-threatening situation for the (highly) vulnerable group. The asphyxiant gases are the first to cause a life-threatening situation for the general group. Within a few minutes after the irritant gases cause a life-threatening situation, the heat would also cause a life-threatening situation at a height of 1.5

meter. Heat doesn't reach the limit value for a life-threatening situation at a height of 0.5 meter.

The asphyxiant gases are the first to cause a fatal situation for the three groups. Within a few minutes after the asphyxiant gases, the heat also causes a fatal situation for the (highly) vulnerable group at a height of 1.5 meter. The irritant gases only reach the limit values for a fatal situation for the highly vulnerable group (2 – 4 minutes later than the asphyxiant gases).

All the fire conditons (visibility, heat, irritant and asphyxiant gases) play a role in the possibility of escape and survivability. Often the limit value is reached for more than one fire conditon.

The amount of oxygen has probably played a role in the speed and intensity of the burning of the mattress. Based on the heat flux, fire might propagate to objects nearby the fire. At the location of the measured heat flux gauges (1.5 meter from the side of the mattress) the heat flux is too low to ingite other objects.

2.3.2 Crib 5 test conventional mattress door open (test 4)

Below the results for test 4 are presented with:

> Photo's of the test (see figure 2.35 till figure 2.38)
> Graphs of measured values during the test (see figure 2.39 till figure 2.41)
> Table with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) (see table 2.6)

Figure 2.35 Start crib 5 test

Figure 2.36 Fire spreads across the mattress

Figure 2.37 Maximum fire size during the test

Figure 2.38 Mattress after the test

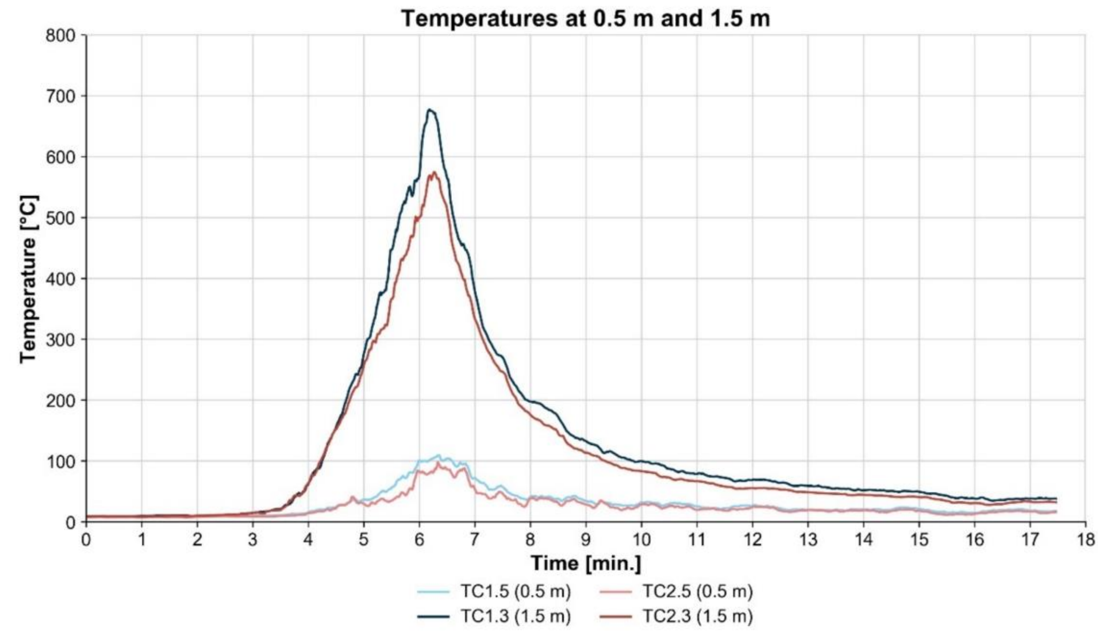


Figure 2.39 Temperatures at 0.5 and 1.5 m height [°C] for test 4

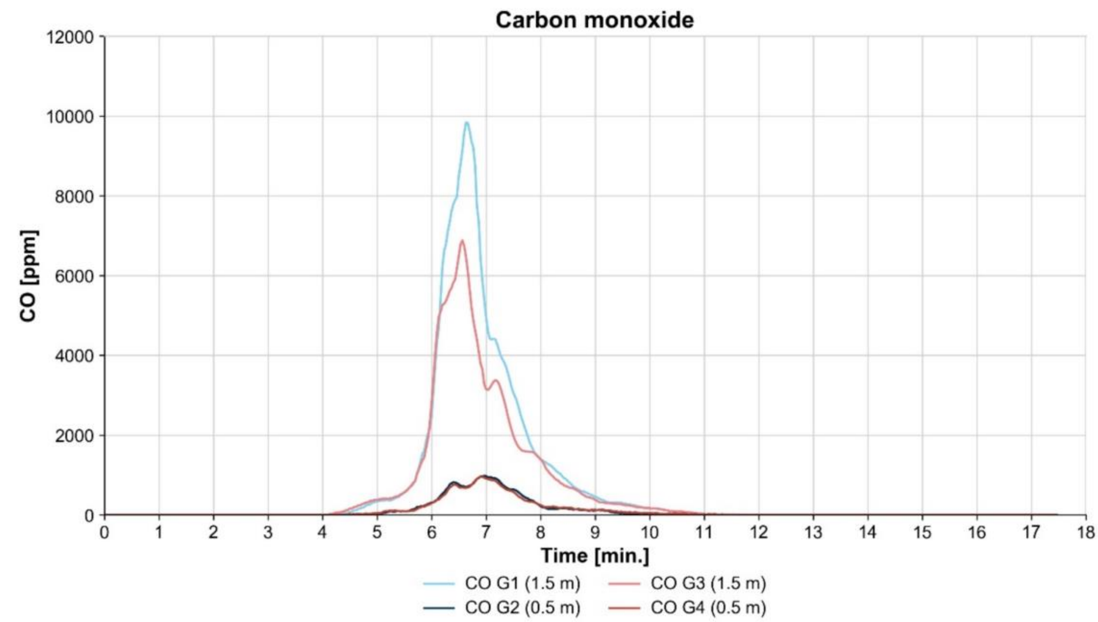


Figure 2.40 Carbon monoxide concentration at 4 locations [ppm] for test 4

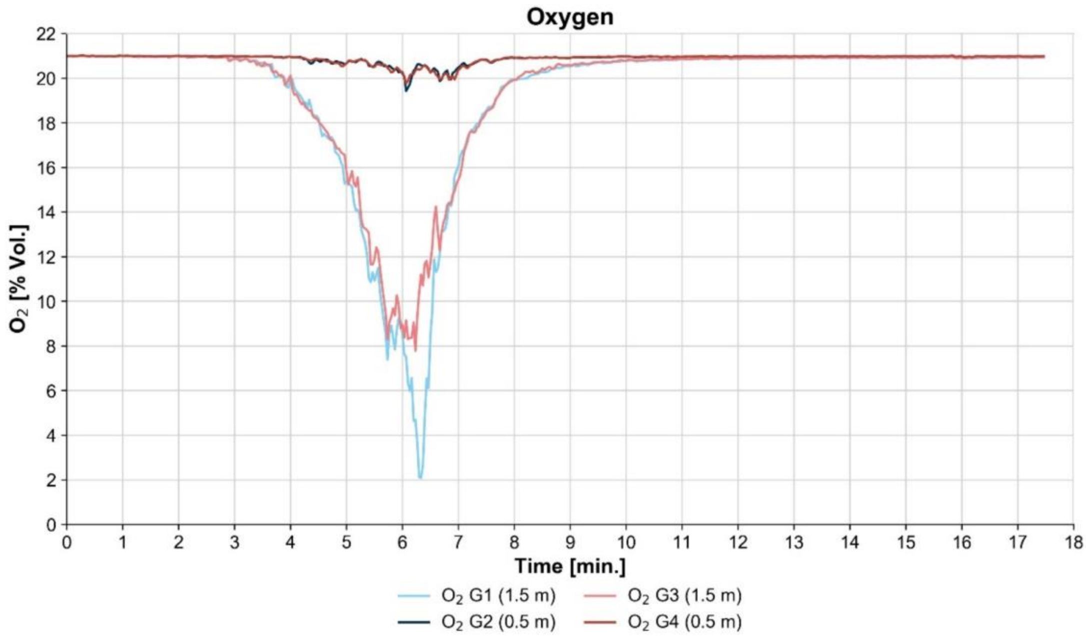


Figure 2.41 Oxygen concentration at 4 locations [% vol.] for test 4

Table 2.6 Times for the possibility of escape and survivability (in minutes) for test 4

Height												
0.5 m	<5	5	5	6	<5	5	6	6	<5	5	6	6
1.5 m	<4	4	4	5	<4	4	5	5	<5	5	6	6

Analysis
During the test, the maximum temperature was more than 700 °C after 6 minutes (level 1.8 m). The maximum carbon monoxide concentration measured was almost 10.000 ppm after 6.5 minutes at a height of 1.5 meter and almost 1000 ppm at a height of 0.5 meter. The minimum oxygen concentration at 1.5 meter was 2 vol. %. At a height of 0.5 meter the minimum oxygen concentration was 19.5 vol. %. The mattress was almost completely burned after 9 minutes. This resulted in a life-threatening situation after 4 - 6 minutes at a height of 1.5 meter and 5 - 6 minutes at a height of 0.5 meter (dependent on the vulnerability of the group). A fatal situation occurred after 5 - 6 minutes at a height of 1.5 meter and 6 minutes at a height of 0.5 meter (dependent on the vulnerability of the group).

The irritant gases and heat reach the limit value to cause an impaired escape at about the same time for the three groups. Visibillity wasn't measured but based on video footage the visibility will probably cause an impaired escape within 4 - 5 minutes at a height of 1.5 meter. At a height of 0.5 meter the visibility is fairly good. At this height a lot of fresh air comes in from the outside towards the fire. In a real building with a hallway connected to the room the situation will probably be different.

The irritant gases are the first to cause a life-threatening situation for the highly vulnerable group at a height of 1.5 meter. For the other groups or the height of 0.5 meter the irritant gases don't reach the limit value for a life-threatening situation. Within 1 minute after the limit value for a life-threatening situation is reached for the highly vulnerable group, the heat also reaches the limit value for a life-threatening situation. Heat and aspyxiant gases reach the limit value at about the same time for the vulnerable and general group at a height of 1.5 meter. At a height of 0.5 meter the limit value for a life-threatening situation is only reached for the fire conditon heat.

The aspyxiant gases and heat reach the limit value to cause a fatal situation at about the same time for the three groups at a height of 1.5 meter. The limit value for a fatal situation isn't reached for the criterion iirritant gases. At a height of 0.5 meter the only fire condition that causes a fatal situation is heat.

All the fire conditions (visibility, heat, irritant and asphyxiant gases) play a role in the possibility of escape and survivability. At a height of 1.5 meter the limit value is often reached for more than one fire condition. At a height of 0.5 meter heat is the determining fire condition for the possibility of escape and survivability. At this height the gas analyzers are in the layer where a lot of fresh air flows enters the room towards the fire. Therefore fairly low concentrations of irritant and aspyxiant gases are measured at a height of 0.5 meter.

The heat flux measured at 1.5 meter is more than 28 kW/m^2. If a fire starts in the mattress, the fire would certainly propagate to other burnable objects in the room.

2.4 Comparison of the new and conventional mattress

In this section the possibility to escape and survivability with the new and the conventional mattress are compared. The results are presented with stacked bars graph with times for the different situations (safe escape, impaired escape, life-threatening situation and fatal situation) for each each group at a height of 0.5 and 1.5 m (see figure 2.42 and figure 2.43). For the comparison the results of the crib 5 tests are used. At the end of this paragraph the differences in the possibility to escape and survivability are analyzed.

Comparison door closed tests

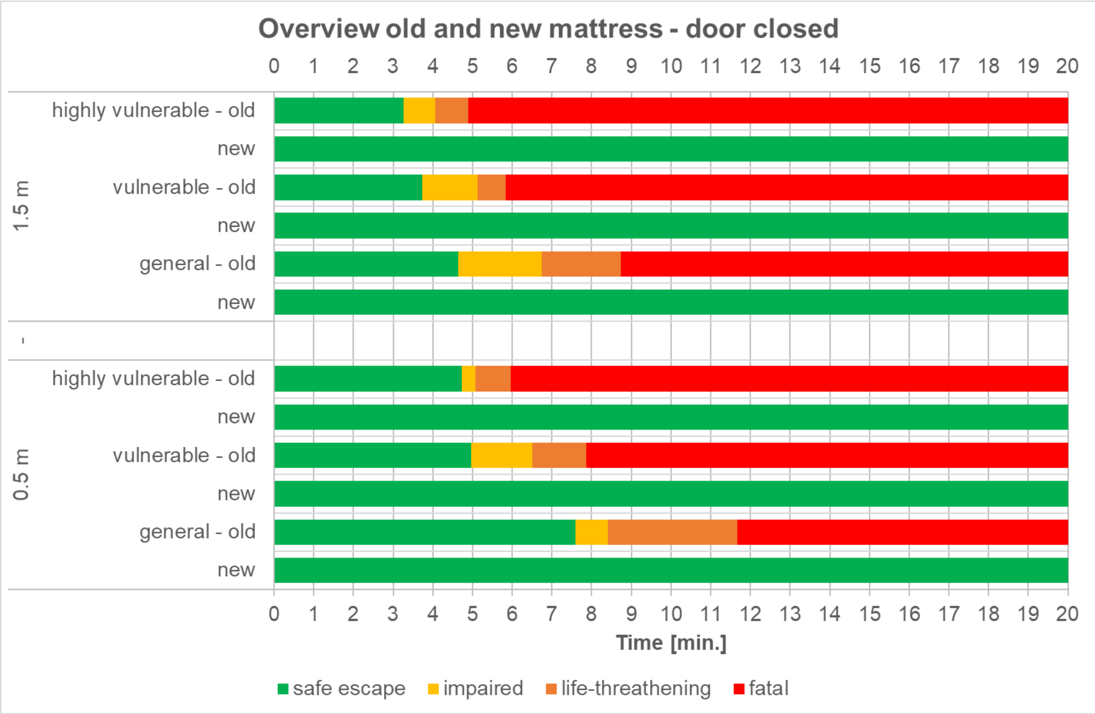


Figure 2.42 Times for the possibility of escape and survivability of the tests with the door closed

Comparison door open tests

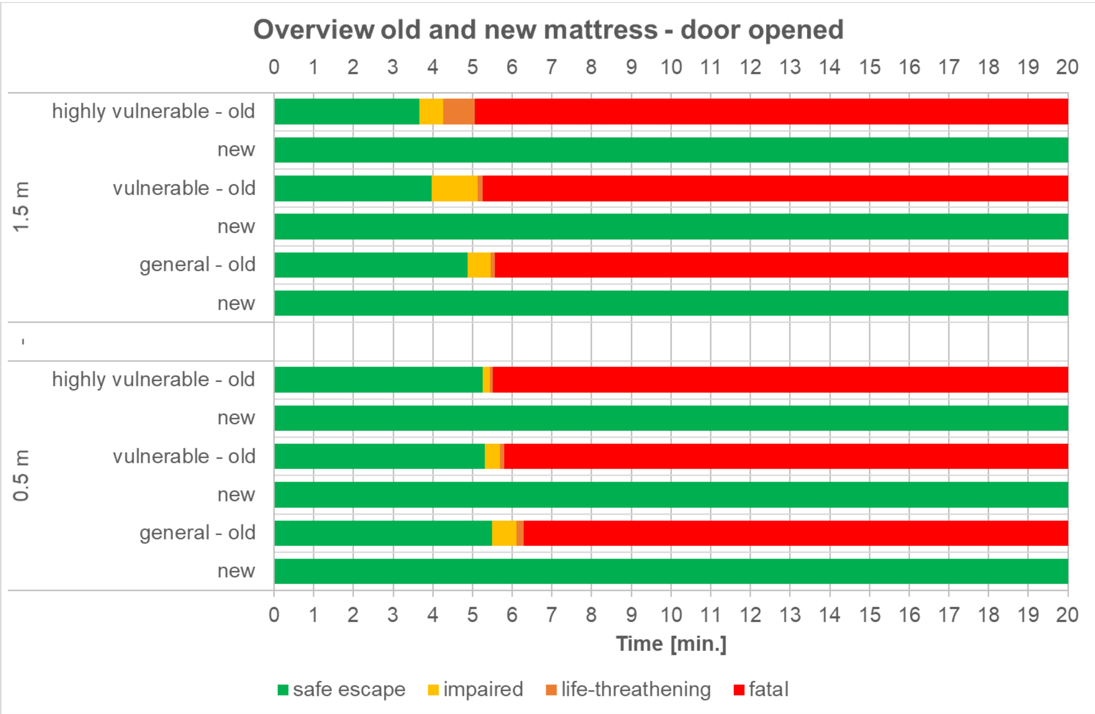


Figure 2.43 Times for the possibility of escape and survivability of the tests with the door open

Analysis

The difference in burning behaviour between the conventional and new mattress is enormous. The new mattress doesn't really contribute to the fire. After the ignition source is burned, the fire dies out. The conventional mattress is completely involved in the fire after 5 – 6 minutes and almost completely burned after 10 minutes in the test with the door open.

With the door of the container closed, the conventional mattress burnes slower, but it is still almost completely burned after 17 minutes. The conventional mattress produces enough heat to let the fire propagate to other burnable items in the room, especially in the test with the door open.

The difference in fire behaviour reflects the difference in the possibility to escape and survivability with the new and conventional mattress. The new mattress has an infinite time for the possibility to escape and survivability. With the conventional mattress there is an impaired escape within 3 - 5 minutes at a height of 1.5 meter and 5 - 8 minutes at a height of 0.5 meter (dependent on the vulnerability of the group and the position of the containerdoor). A life-threatening situation occurs after 4 - 7 minutes at a height of 1.5 meter and 5 – 9 minutes at a height of 0.5 meter (dependent on the vulnerability of the group and the position of the containerdoor). A fatal situation occurrs after 5 - 9 minutes at a height of 1.5 meter and 6 – 12 minutes at a height of 0.5 meter (dependent on the vulnerability of the group and the position of the containerdoor). Just one conventional mattress inside a room of about 14 m^2 is in itself enough to cause a fatal situation in case of a fire.

3 Findings

Research question 1:

What is the fire behaviour in a bedroom environment of the new and conventional mattresses of Royal Auping B.V. when exposed to common test ignition sources such as a cigarette and crib 5?

Both the conventional and the new mattress are not ignited in the cigarette test. The new mattress does not really contribute to the fire in the crib 5 test. After the crib 5 is burned the fire stops. Even with a larger ignition source (100 ml flammable liquid), the fire in the new mattress dies out after the flammable liquid is burned. For the conventional mattress it is a complete different situation. The conventinal mattress burns fast and intense. It is completely burned away after 10 to 17 minutes (door open and door closed). The conventional mattress produces enough heat to let the fire propagate to other burnable items in the room, especially in the test with the door open.

Research question 2:

What is the possibility of escape and survivability in a bedroom environment when only the new or conventional mattress of Royal Auping B.V. is burning?

With only the new mattress involved in the fire, a person has an infinite time for the possibility to escape and survivability. With the conventional mattress involved in a fire, there is an impaired escape after 3 - 8 minutes, a life-threatening situation after 4 -9 minutes and a fatal situation after 5 - 12 minutes (dependent on measurement height, the vulnerability of the group and the position of the containerdoor). Only one conventional mattress inside a room of about 14 m^2 in itself is enough to cause a fatal situation.

4 Discussion

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

The results of this research are of course only valid for the configurations studied in this research and strictly speaking cannot be generalized, except with common sense and caution. There are some limitations that can be mentioned:

- Only 4 objects (two new and two old mattresses) are used in the experiments. It is uncertain if the old mattresses are representative for upholstered mattresses. There is also an uncertainty about the results of each test, because the tests per object were not repeated.
- The fire room has the dimensions of a bedroom (14 m^2). Different room dimensions could lead to different results. The material of the enclosure (steel container) is of influence of the parameter heat. Other materials (brick) could lead to different results. The door of the container is larger then an average bedroom 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 contain local effects.
- 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 (experiments) is that there are always some phenomena or uncertainties in the data that cannot be explained. It is not a laboratorium environment. The advantage of the chosen methodology is that a good impression can be obtained.
- The limit values used to determine the possibility of escape and survivability are arbitrary as mentioned in the report. Other values could lead to different conclusions. The limit values are used in particular to provide insight into the differences.
- In the experiments visibility is not measured. The visibility during the experiments might lead other times for the possibility of escape.

Taking into account these limitations, the results regarding the fire behaviour, possibility of escape and survivability may differ from actual residential fires. However this research provides a good impression of the fire behaviour of *new and conventional mattresses of Royal Auping B.V.* It is also a good starting point from which the fire safety of mattresses can be increased.

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.

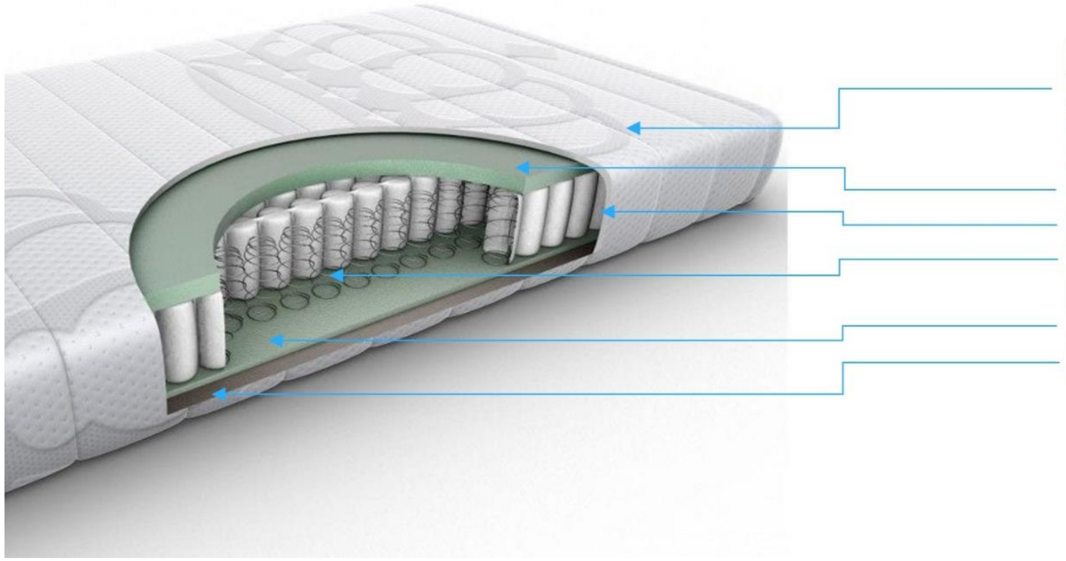
ISO 13571. (2012). *Life-threatening components of fire - Guidelines for the estimation of time to compromised tenability in fires.* Geneva: International Organization for Standardization.

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 Cross-sections of the mattresses

Cross-section and material composition of the conventional mattress



Part	Color	Material composition
ticking textile	white	36% Viscose / 64% Polyester textile knitted fabric
ticking filling	white	10mm PU foam
ticking textile	white	100% PET polyester
comfort layer	green	30mm PU foam
sides	white	100x115mm PU foam
springs	metal	steel
pockets	white	PP fleece
bottom layer	white	10mm PU foam
bottom layer	grey	100% bi-co polyester non woven

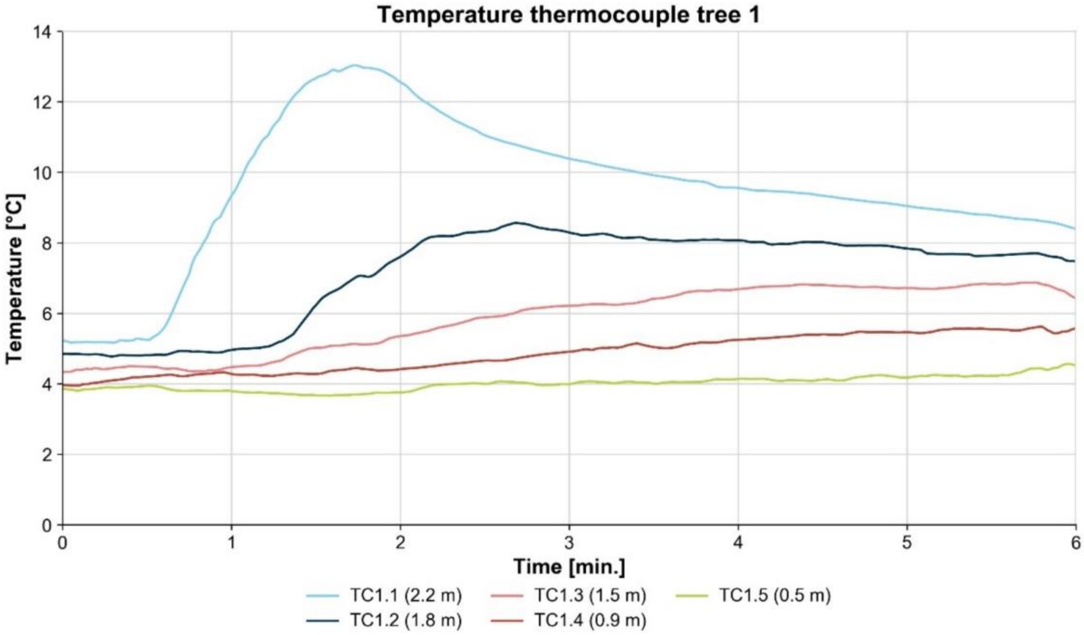
Cross-section and material composition of the new mattress (Auping Evolve)

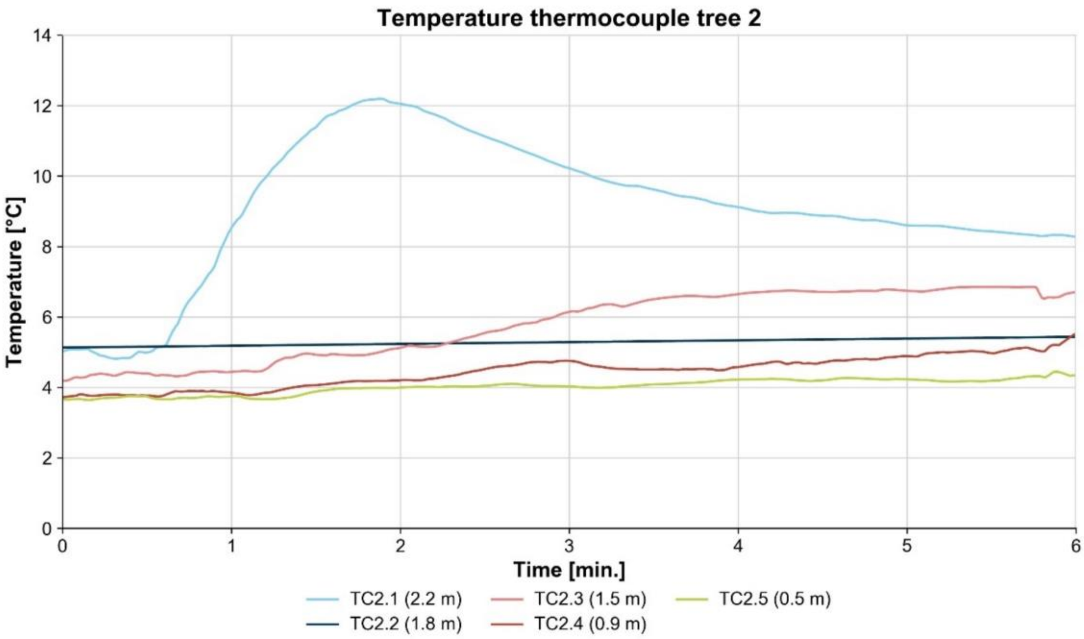
Part	Color	Material composition
ticking textile	white	100% PET polyester knitted fabric
zipper	dark blue	100% PET polyester
zipper slider	dark blue	aluminum
ticking textile	light blue	100% PET polyester knitted fabric
filling for border	white	100% bi-co polyester non woven
sides	white	100% bi-co polyester non woven
spacer fabric	white	100% PET polyester
spacer fabric	white	100% PET polyester
springs	metal	steel
pockets	white	100% bi-co polyester non woven
bottom layer	white	100% bi-co polyester non woven
bottom layer	grey	100% bi-co polyester non woven
adhesive	white	100% polyester

Appendix 2 Overview measured data per sensor and test

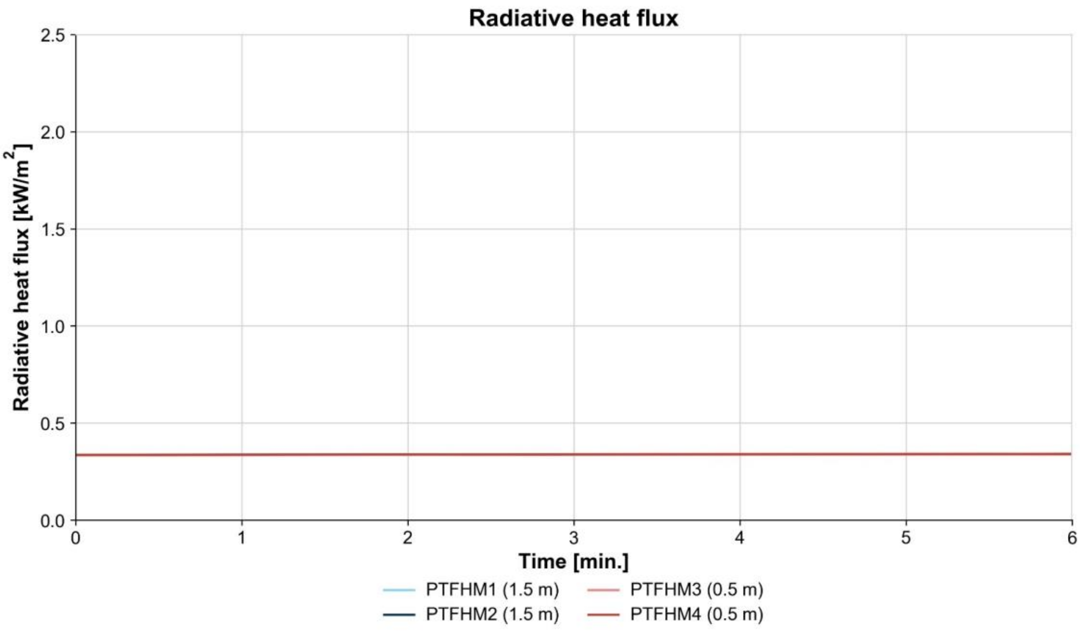
Test 1a new mattress crib 5 (door closed)

Heat

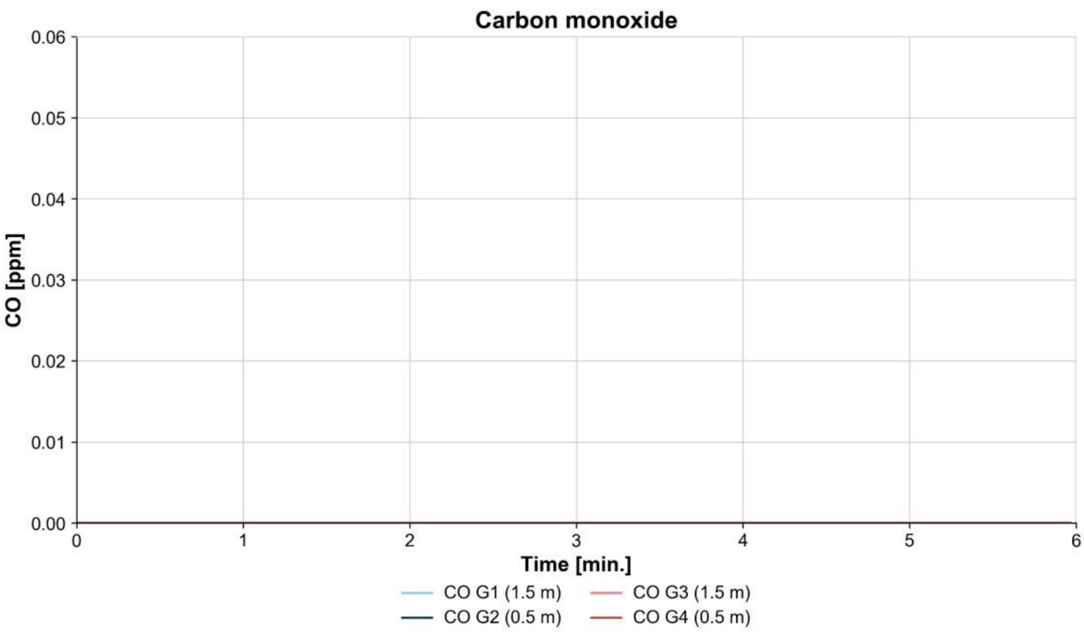


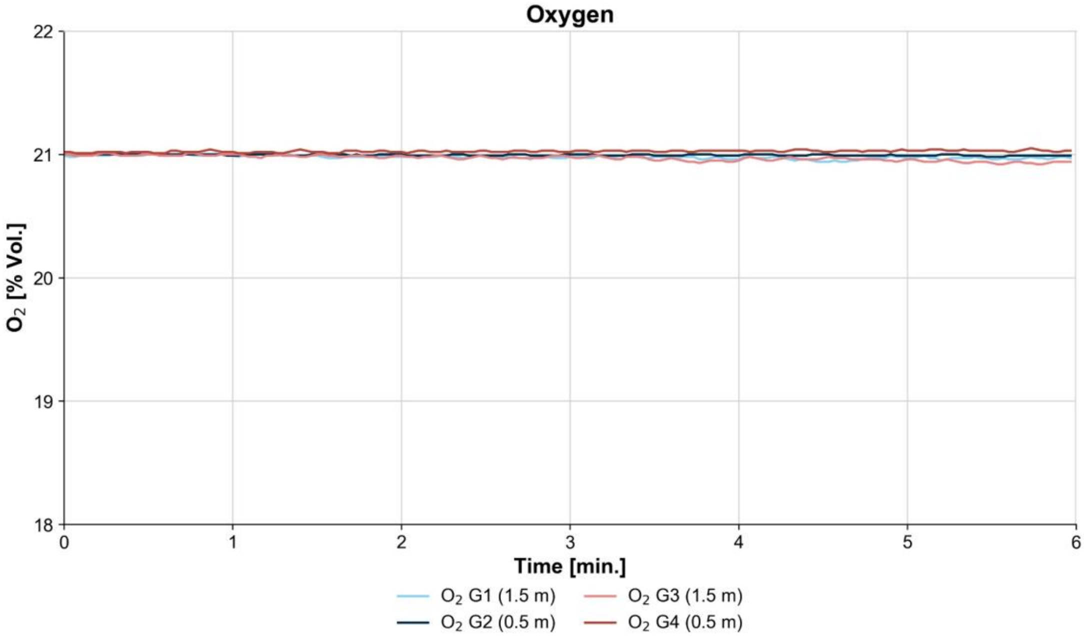


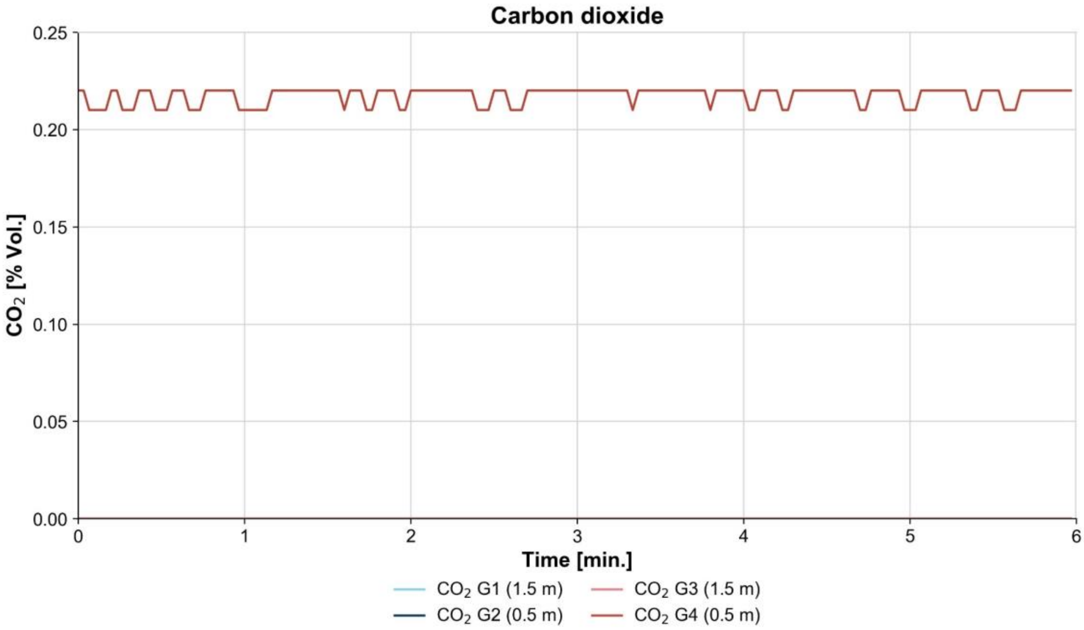
Radiative heat flux

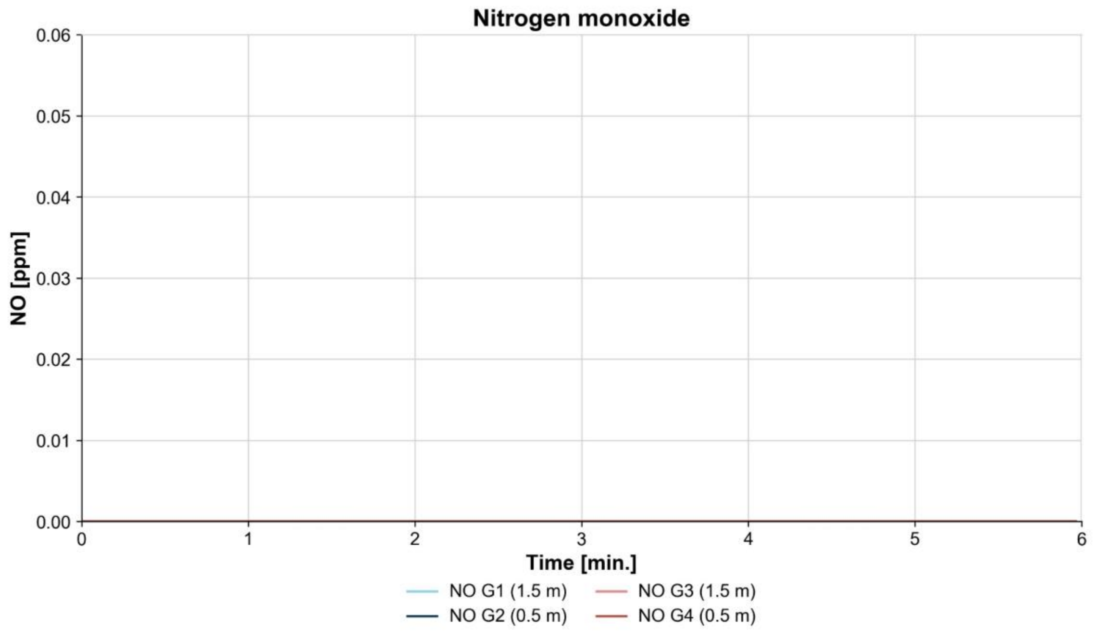

Radiative heat flux
Radiative heat flux [kW/m2]
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
Time [min.]
PTFHM1 (1.5 m)
PTFHM3 (0.5 m)
PTFHM2 (1.5 m)
PTFHM4 (0.5 m)

Gases

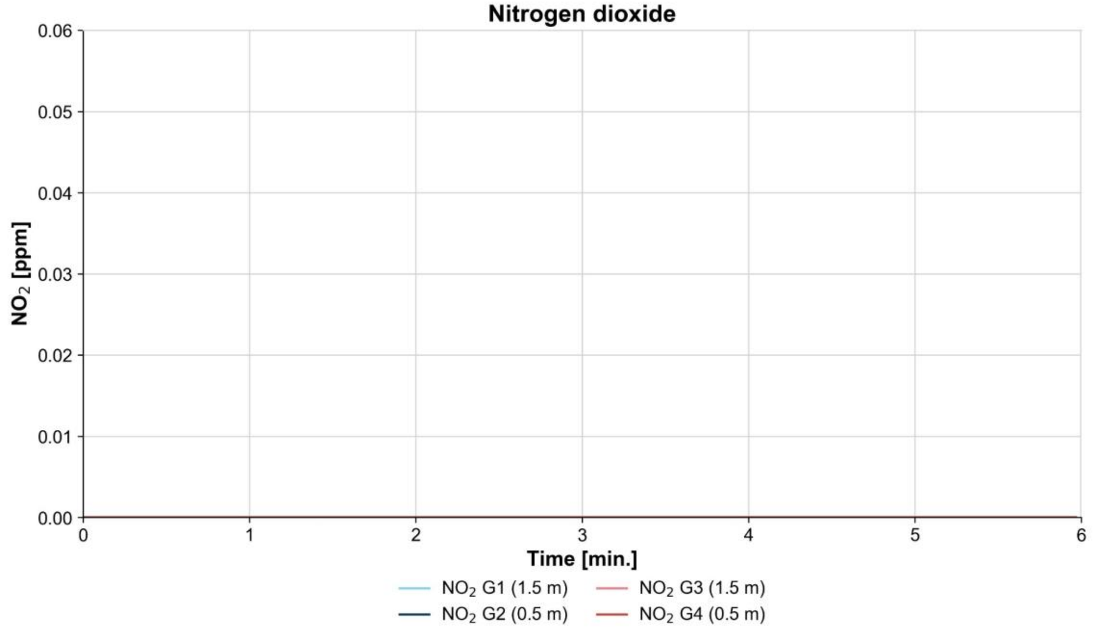

Carbon monoxide
CO [ppm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
Time [min.]
CO G1 (1.5 m)
CO G3 (1.5 m)
CO G2 (0.5 m)
CO G4 (0.5 m)


Oxygen
22
21
20
19
18
O2 [% Vol.]
0
1
2
3
4
5
6
Time [min.]
O2 G1 (1.5 m)
O2 G2 (0.5 m)
O2 G3 (1.5 m)
O2 G4 (0.5 m)

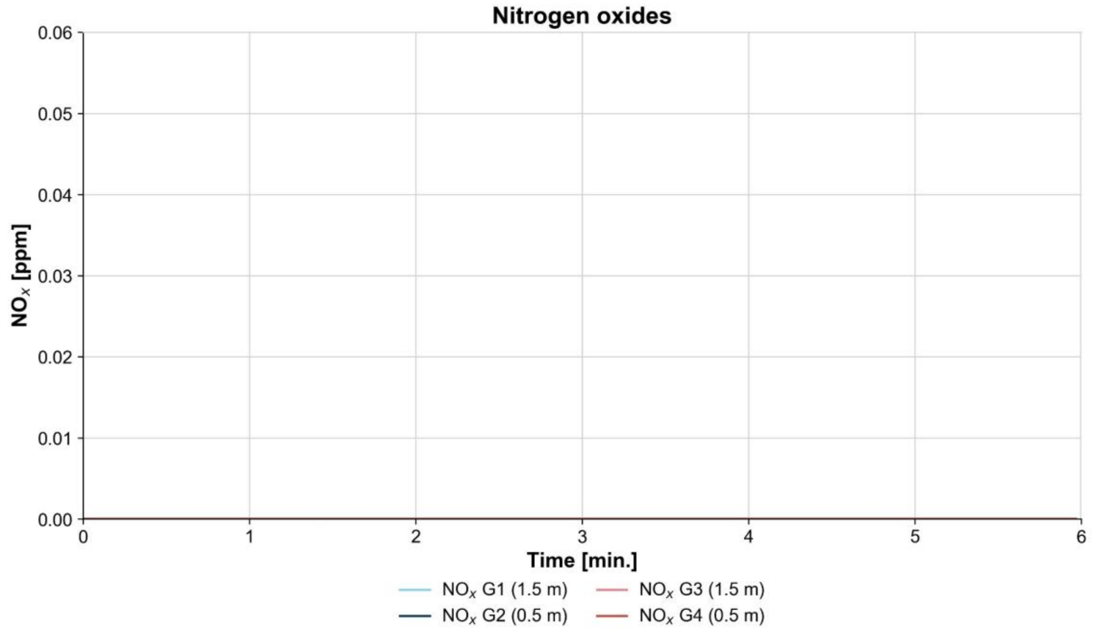

Carbon dioxide
0.25
0.20
0.15
0.10
0.05
0.00
CO2 [% Vol.]
0
1
2
3
4
5
6
Time [min.]
CO2 G1 (1.5 m)
CO2 G2 (0.5 m)
CO2 G3 (1.5 m)
CO2 G4 (0.5 m)



Nitrogen monoxide
NO [ppm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)

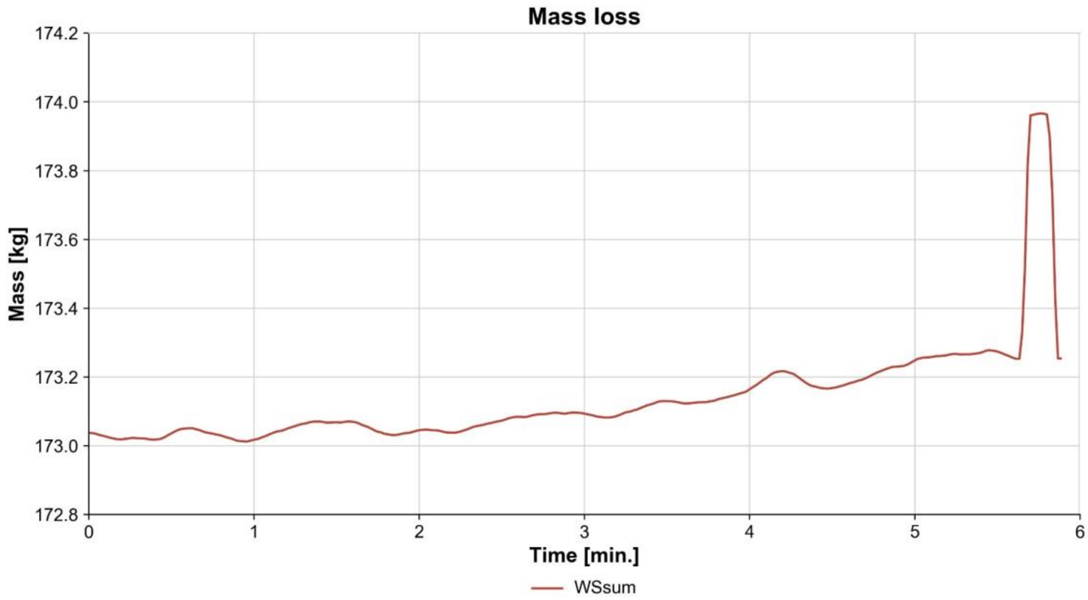


Nitrogen dioxide
NO_2 [ppm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
Time [min.]
NO_2 G1 (1.5 m)
NO_2 G3 (1.5 m)
NO_2 G2 (0.5 m)
NO_2 G4 (0.5 m)



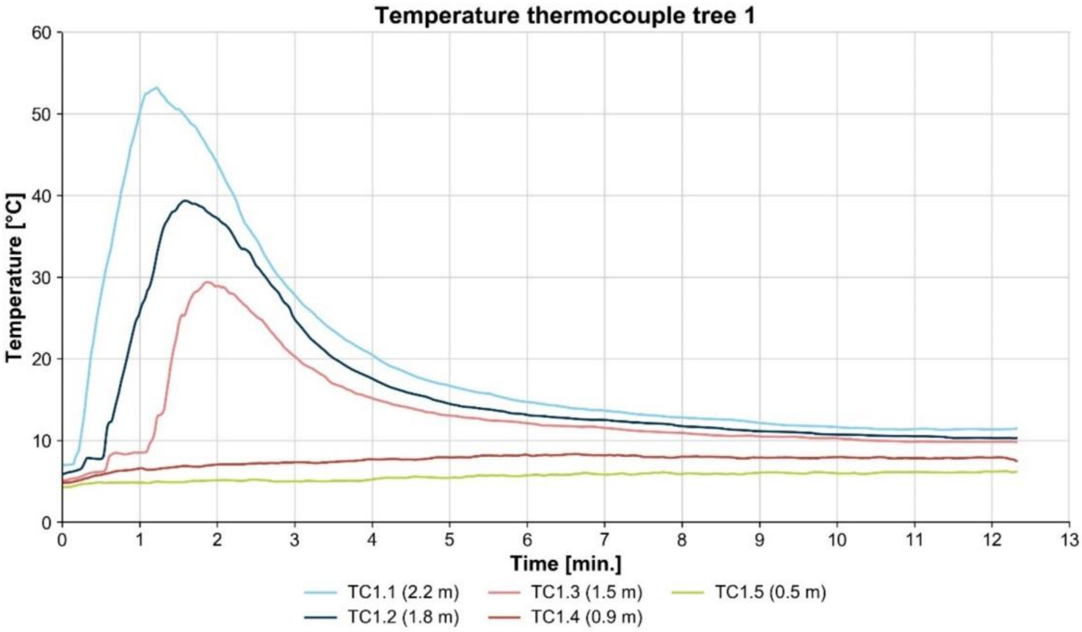
Nitrogen oxides
NO_x [ppm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
1
2
3
4
5
6
Time [min.]
NO_x G1 (1.5 m)
NO_x G3 (1.5 m)
NO_x G2 (0.5 m)
NO_x G4 (0.5 m)

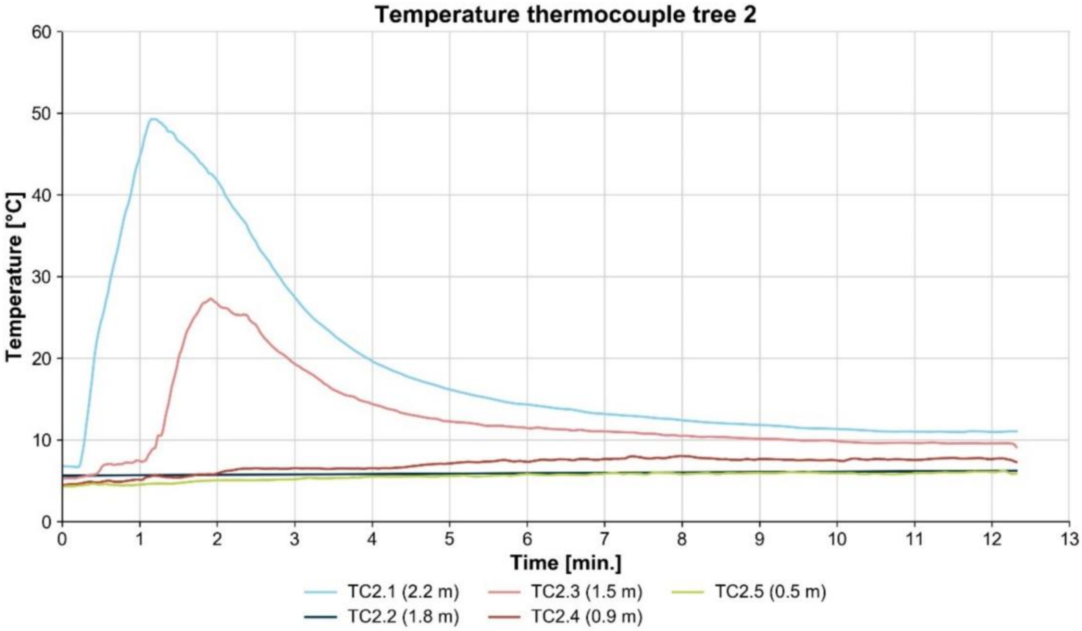
Mass loss


Mass loss
174.2
174.0
173.8
173.6
173.4
173.2
173.0
172.8
Mass [kg]
0
1
2
3
4
5
6
Time [min.]
WSsum

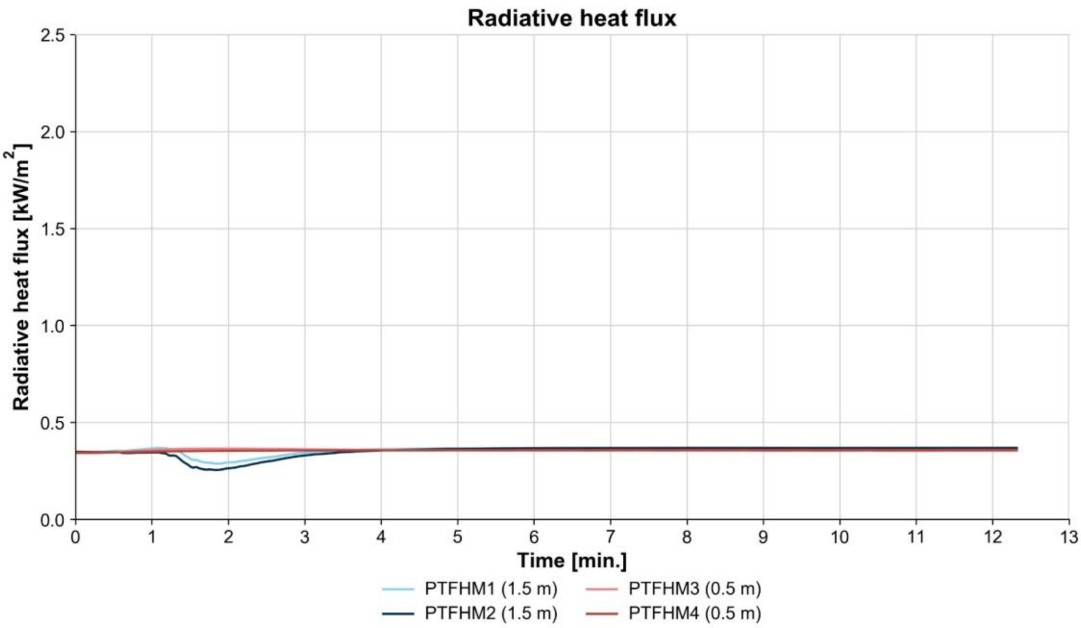
Test 1b new mattress isopropanol (door closed)

Heat

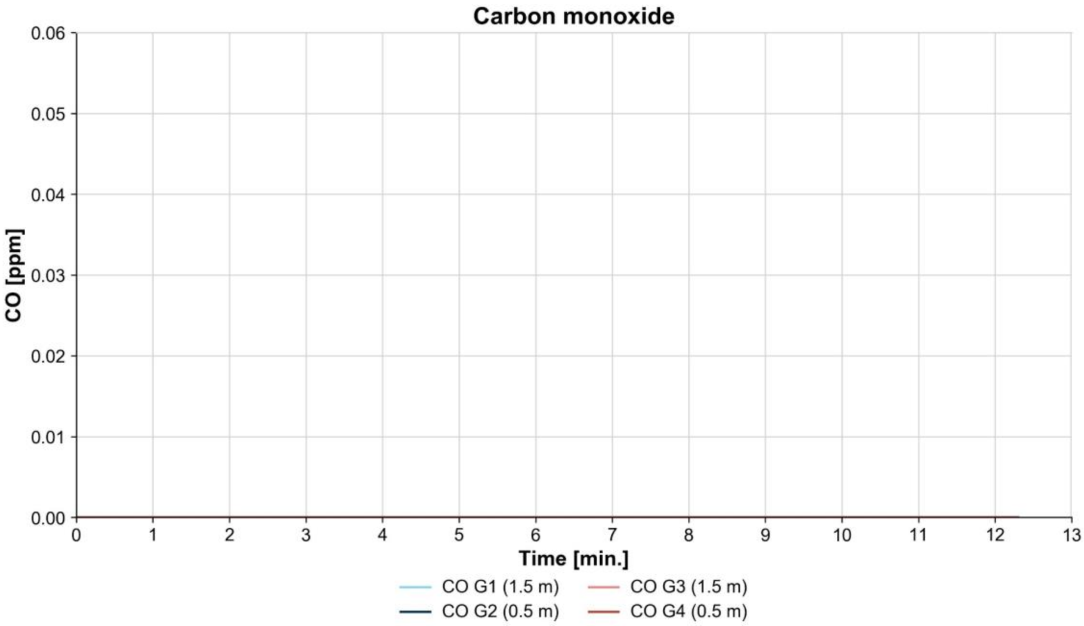


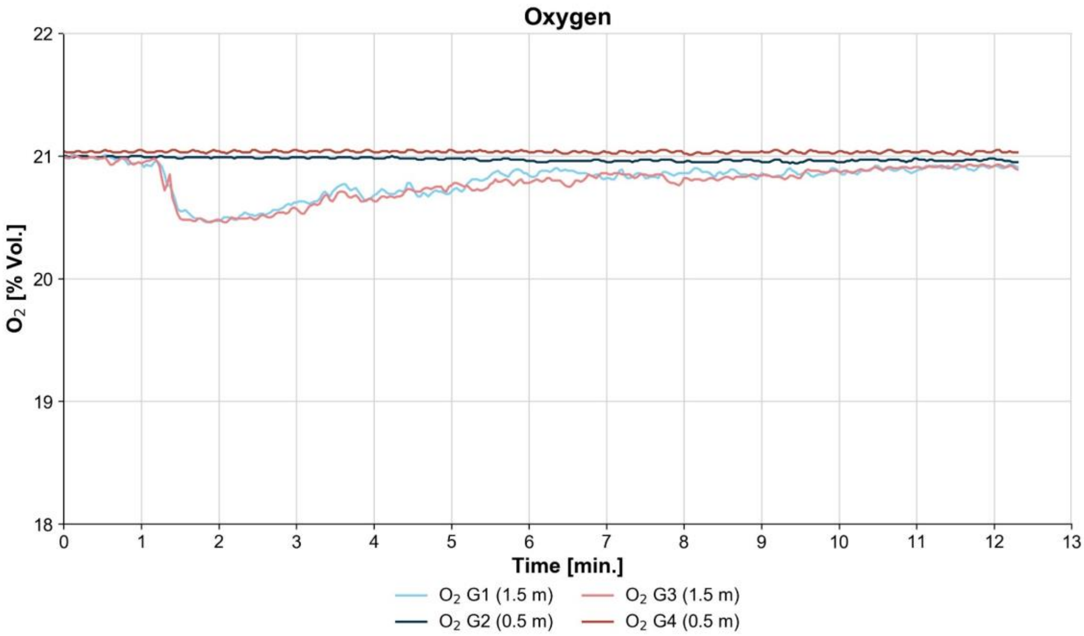


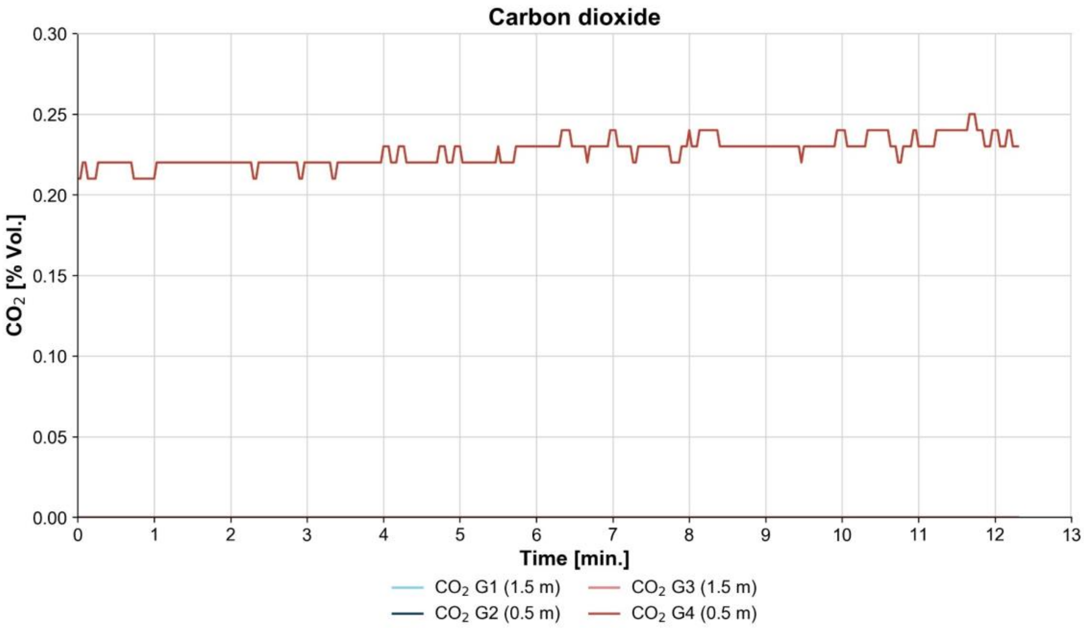
Radiative heat flux

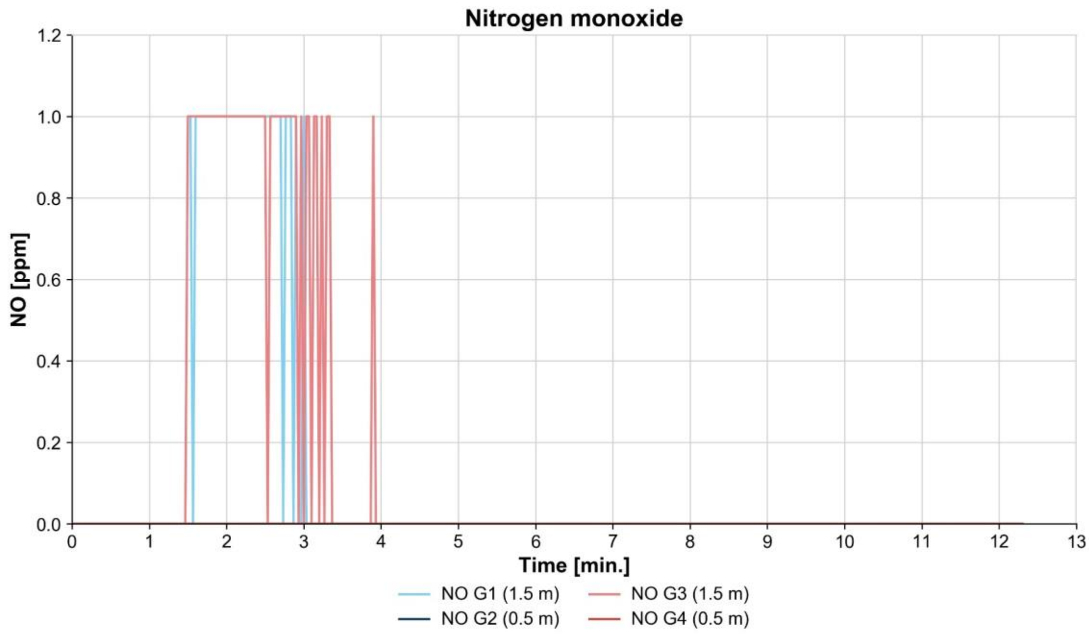

Radiative heat flux
Radiative heat flux [kW/m²]
2.5
2.0
1.5
1.0
0.5
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Time [min.]
PTFHM1 (1.5 m)
PTFHM3 (0.5 m)
PTFHM2 (1.5 m)
PTFHM4 (0.5 m)

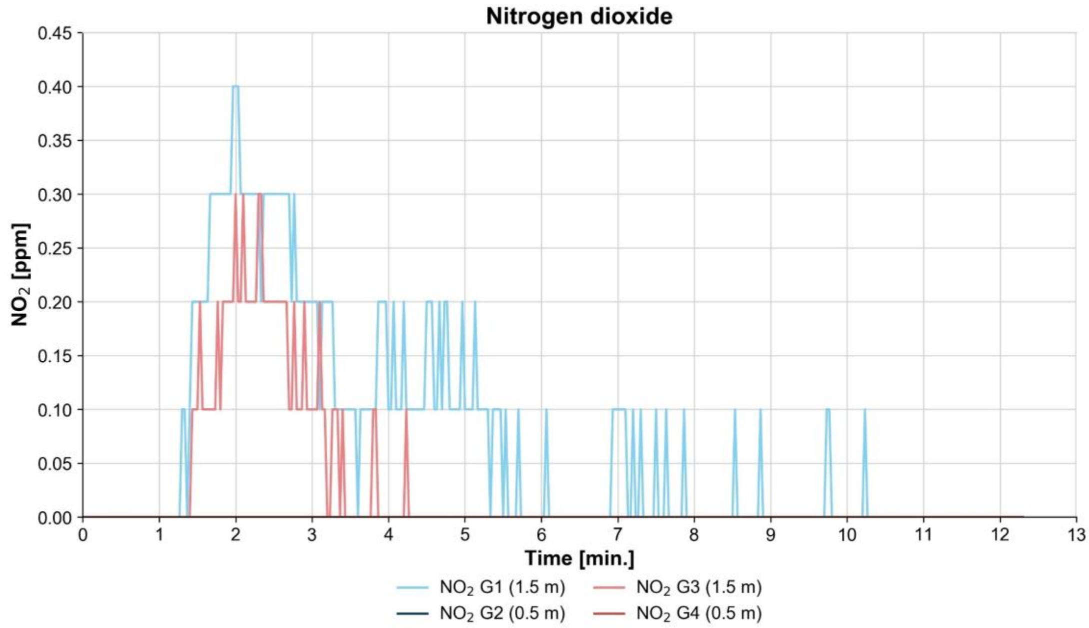
Gases

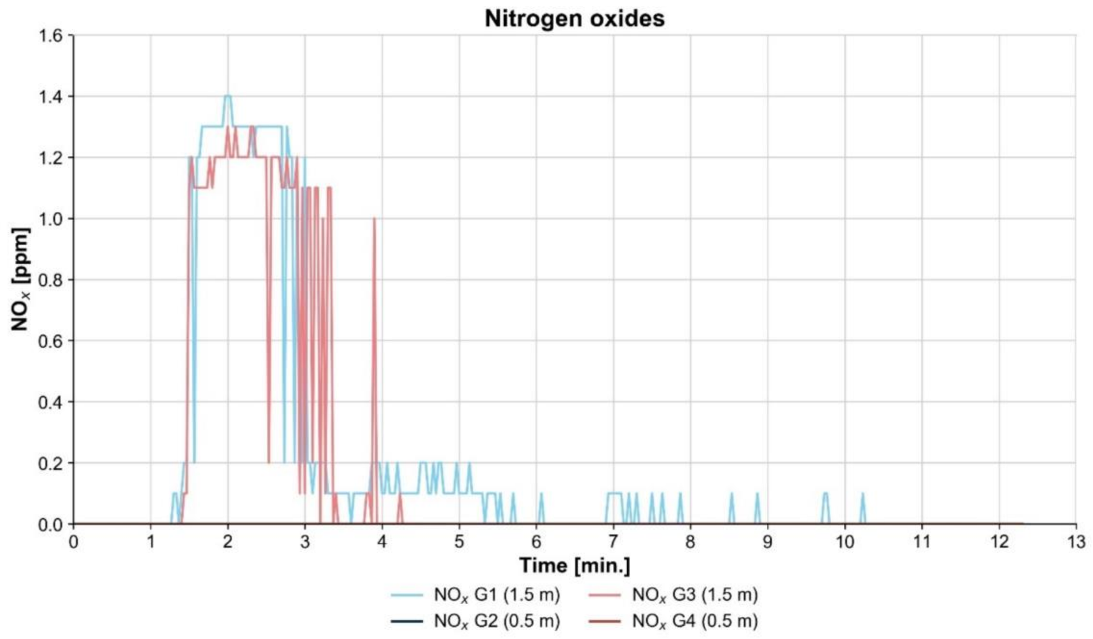

Carbon monoxide
CO [ppm]
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Time [min.]
CO G1 (1.5 m)
CO G3 (1.5 m)
CO G2 (0.5 m)
CO G4 (0.5 m)


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)

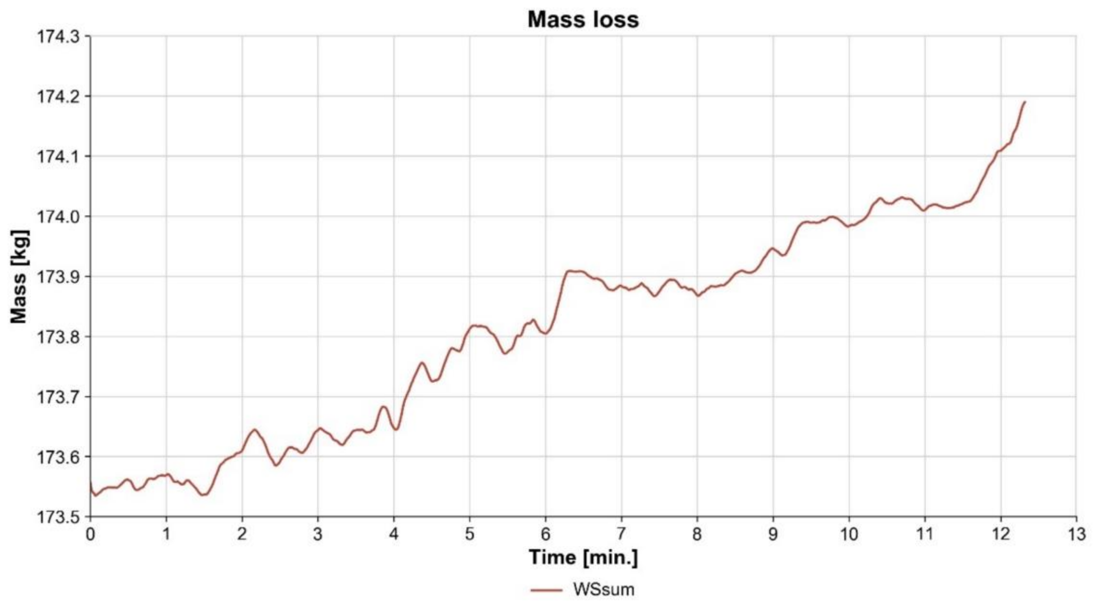

Carbon dioxide
CO_2 [% Vol.]
Time [min.]
CO_2 G1 (1.5 m)
CO_2 G3 (1.5 m)
CO_2 G2 (0.5 m)
CO_2 G4 (0.5 m)


Nitrogen monoxide
NO [ppm]
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)

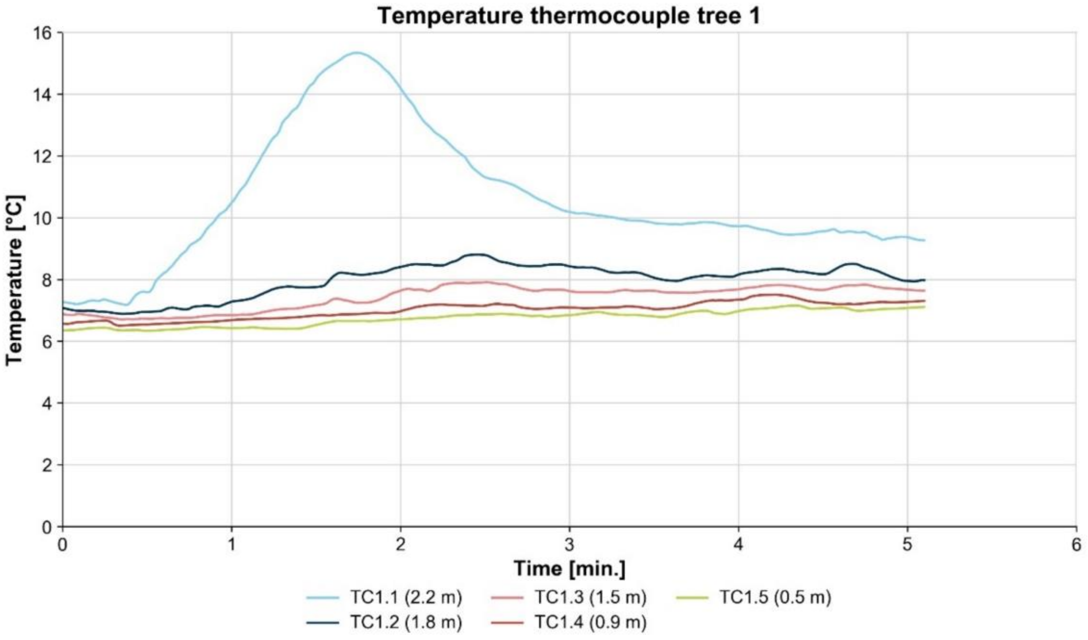

Nitrogen oxides
NOx [ppm]
Time [min.]
NOx G1 (1.5 m)
NOx G3 (1.5 m)
NOx G2 (0.5 m)
NOx G4 (0.5 m)

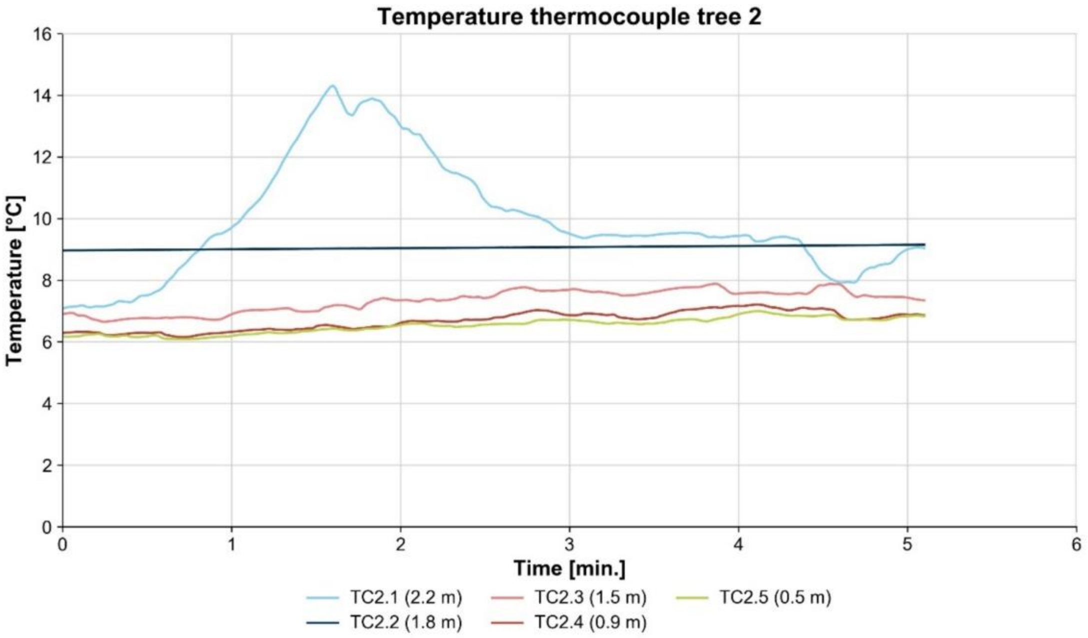
Mass loss


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

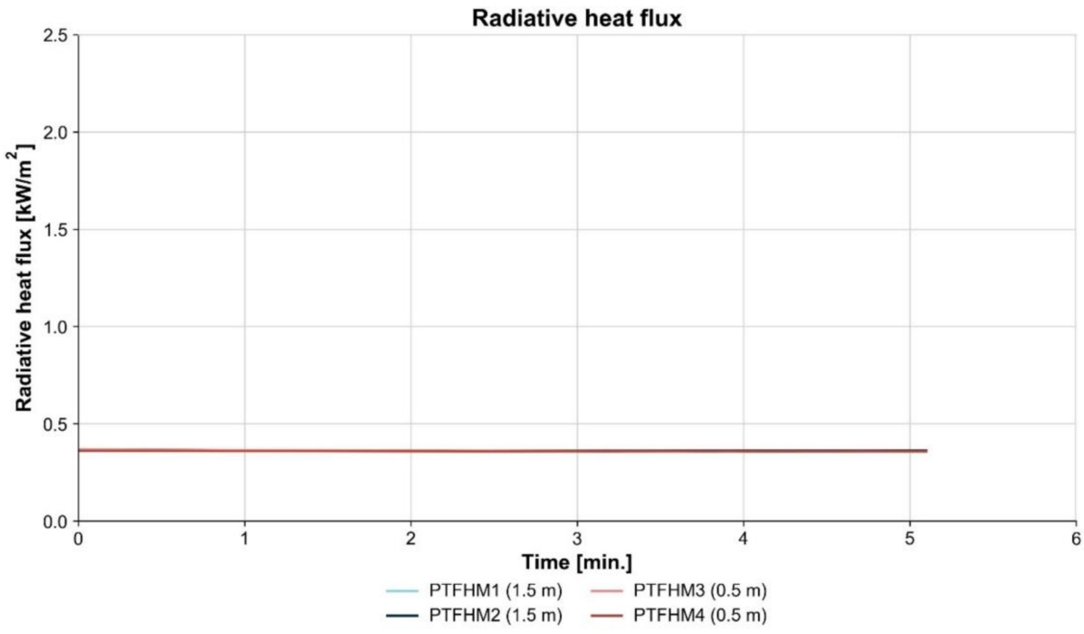
Test 2a new mattress crib 5 (door open)

Heat

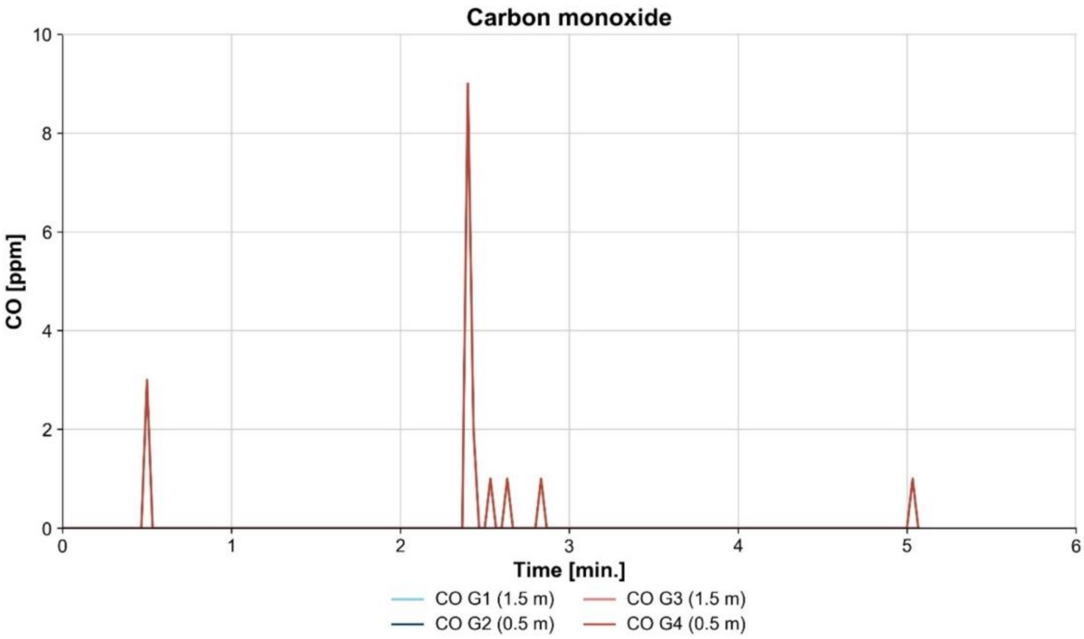


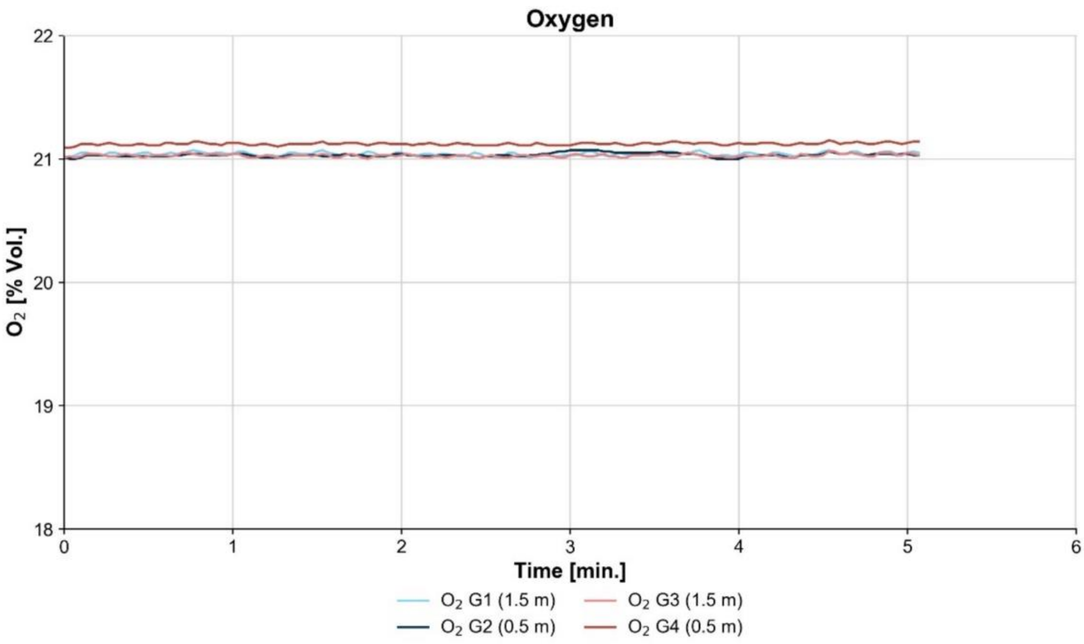


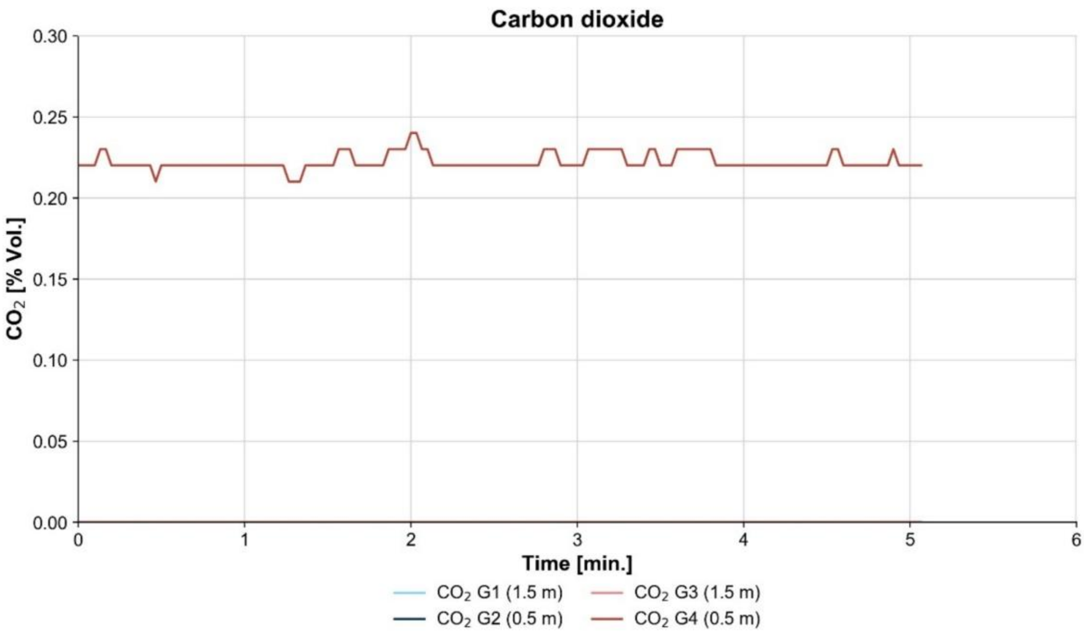
Radiative heat flux

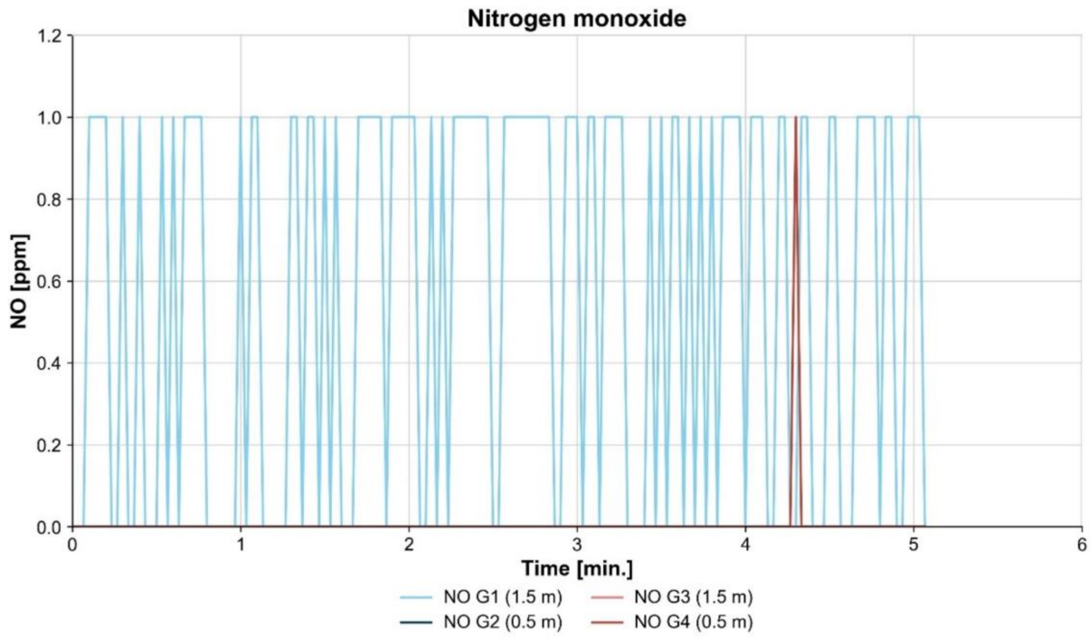

Radiative heat flux
Radiative heat flux [kW/m2]
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

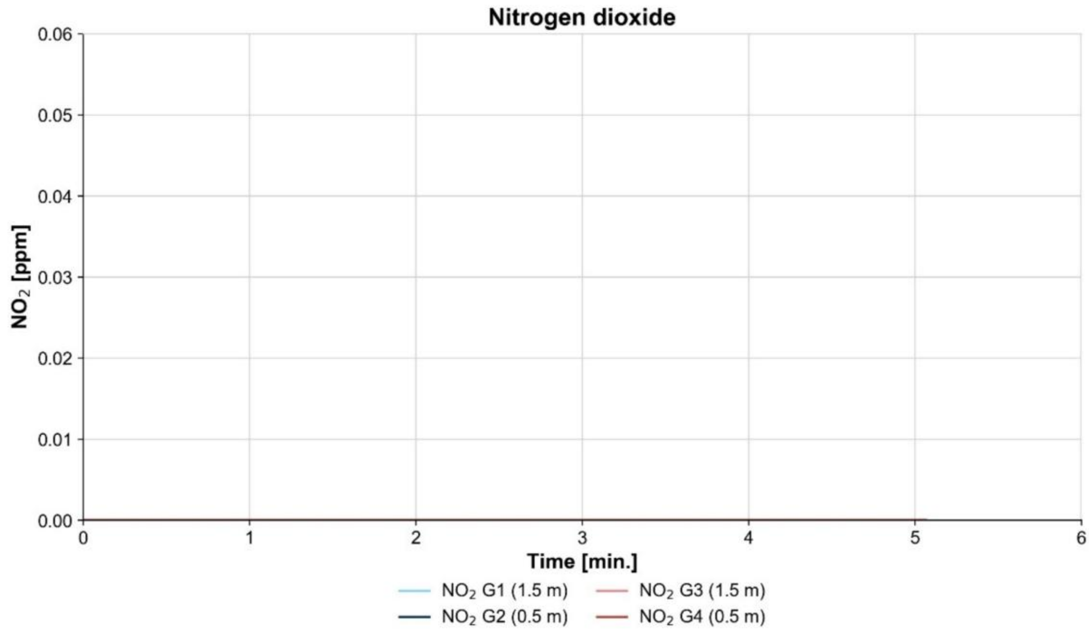
Gases

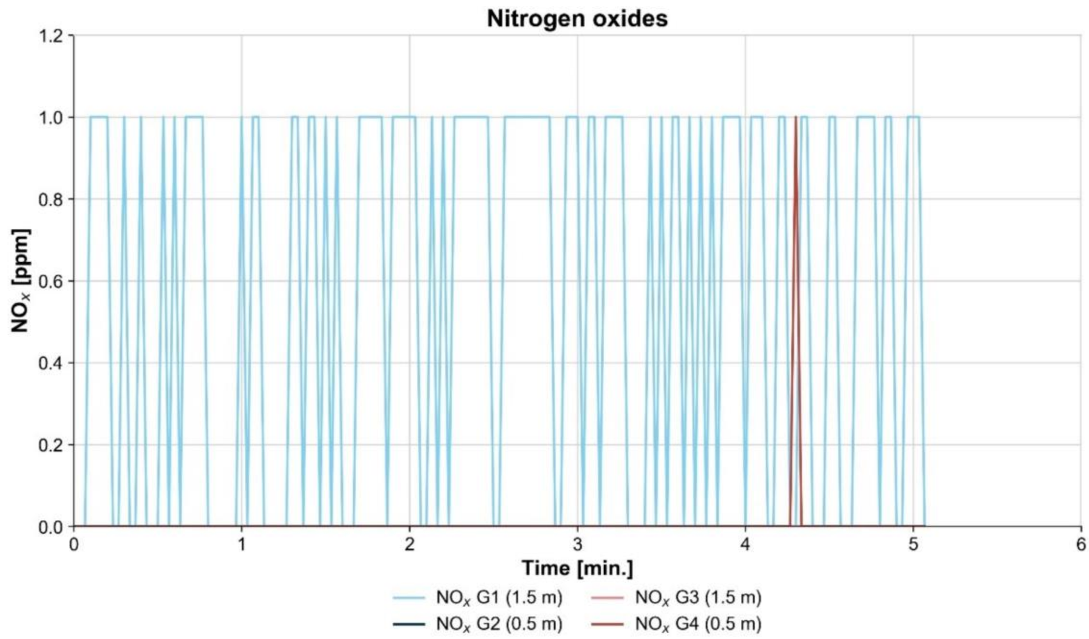

Carbon monoxide
CO [ppm]
10
8
6
4
2
0
0
1
2
3
4
5
6
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
22
21
20
19
18
O_2 [% Vol.]
0
1
2
3
4
5
6
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
0.30
0.25
0.20
0.15
0.10
0.05
0.00
CO_2 [% Vol.]
0
1
2
3
4
5
6
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)

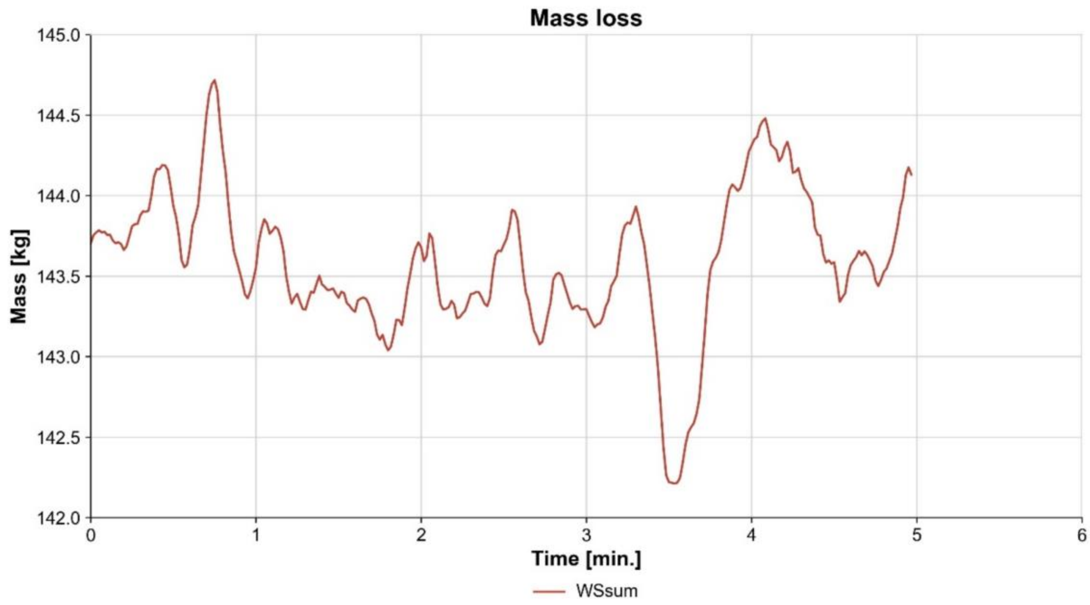

Nitrogen monoxide
NO [ppm]
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)


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
1.2
1.0
0.8
0.6
0.4
0.2
0.0
NO$_x$ [ppm]
0
1
2
3
4
5
6
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)

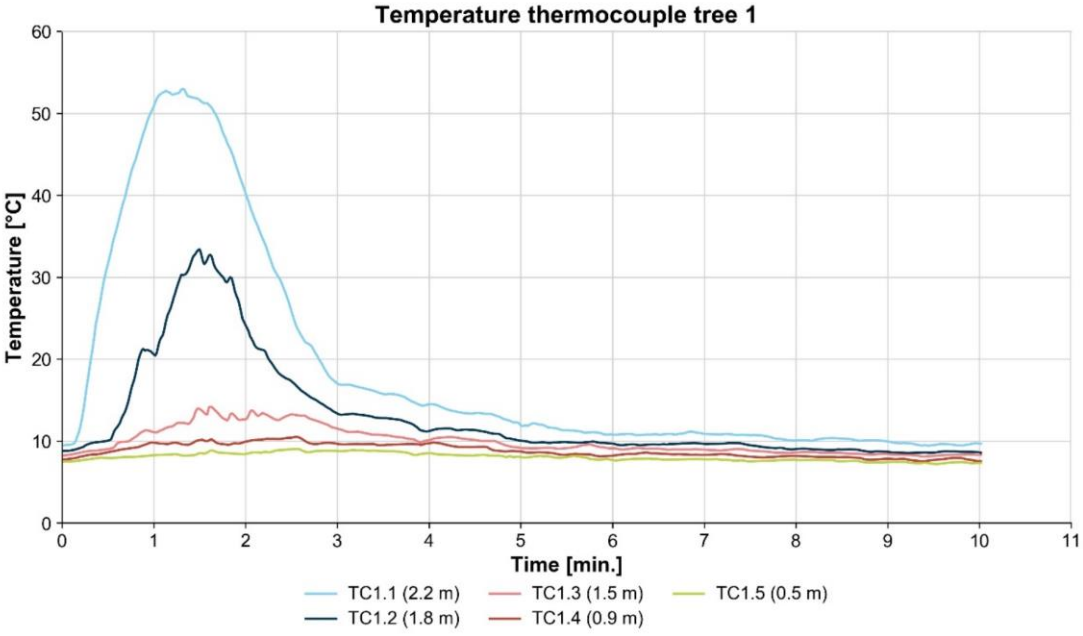
Mass loss

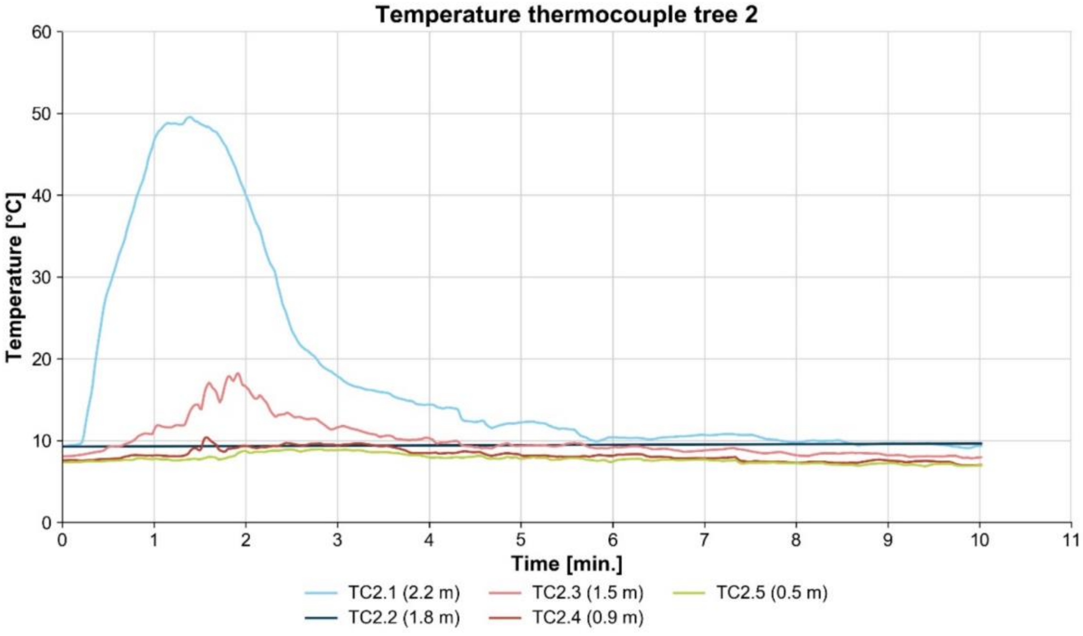


Mass loss
145.0
144.5
144.0
143.5
143.0
142.5
142.0
Mass [kg]
0
1
2
3
4
5
6
Time [min.]
WSsum

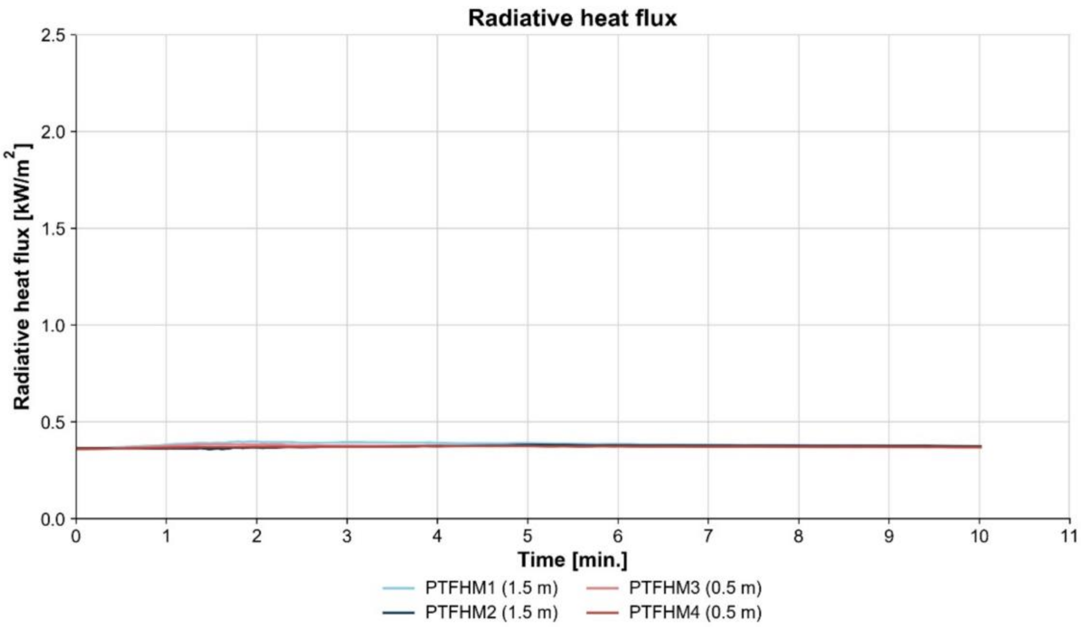
Test 2b new mattress isopropanol (door open)

Heat

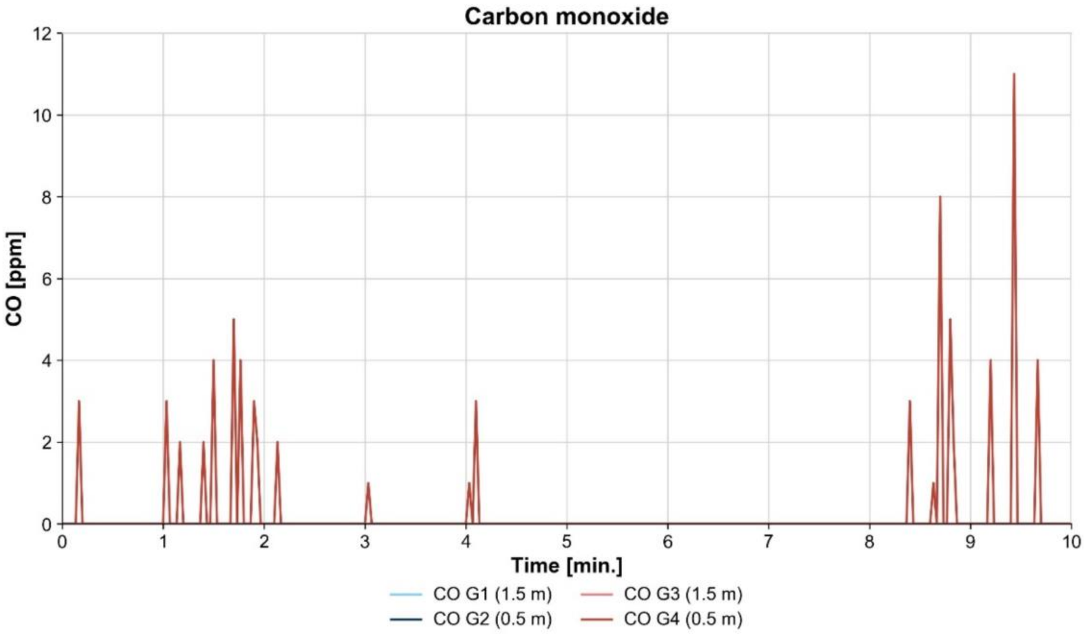


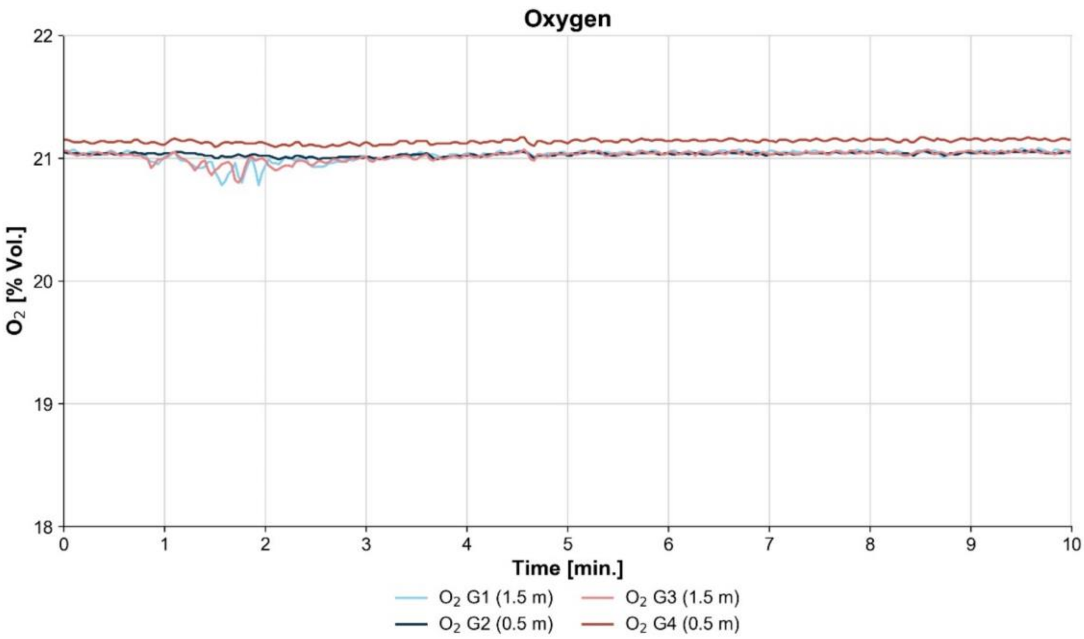


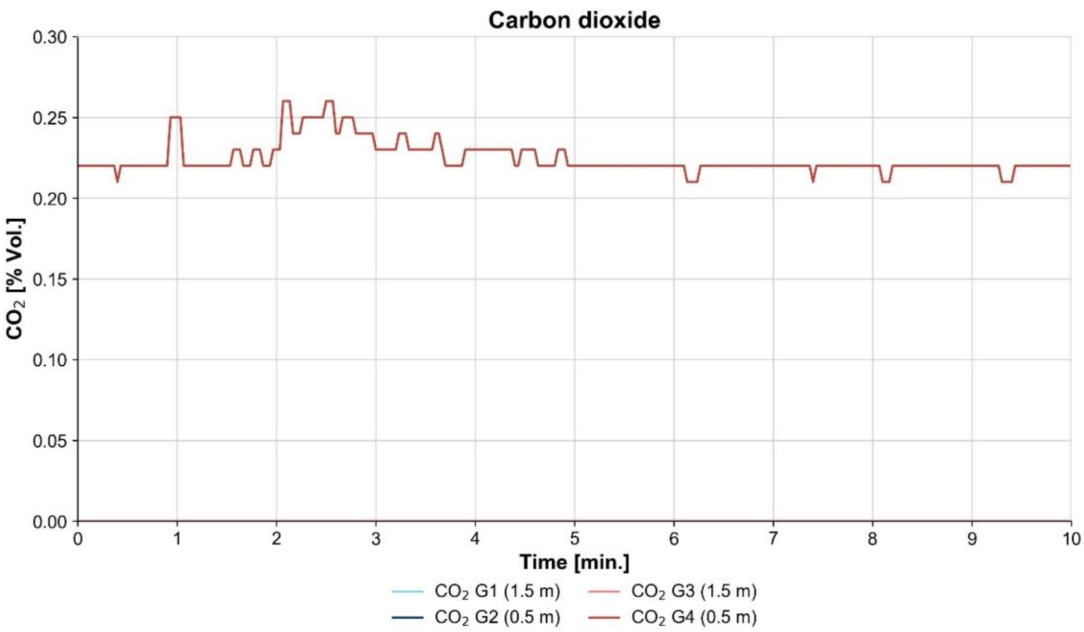
Radiative heat flux

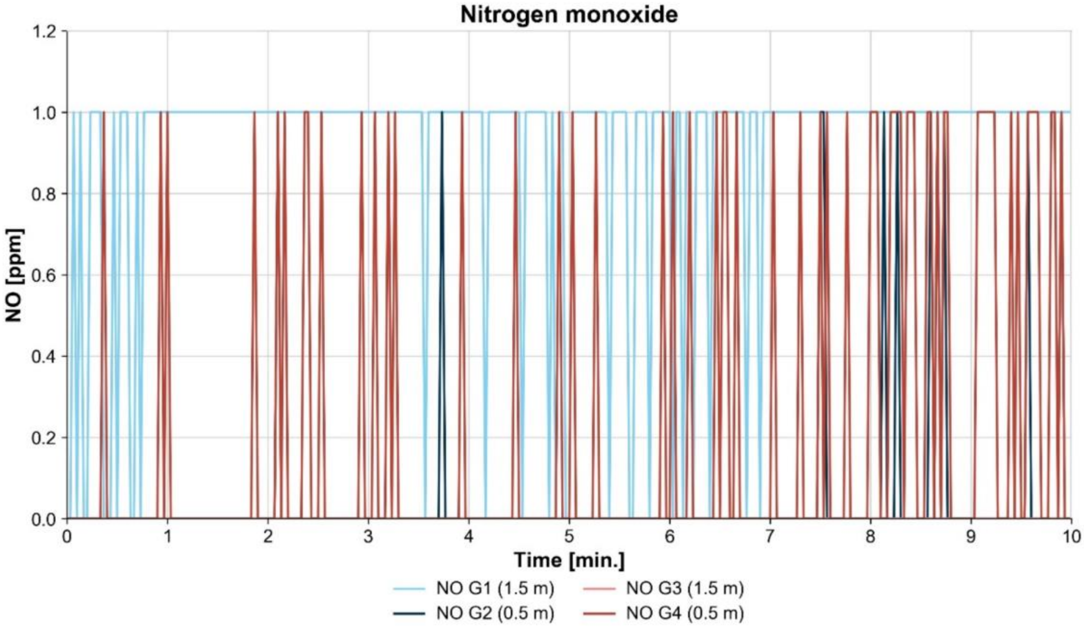

Radiative heat flux
Radiative heat flux [kW/m2]
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

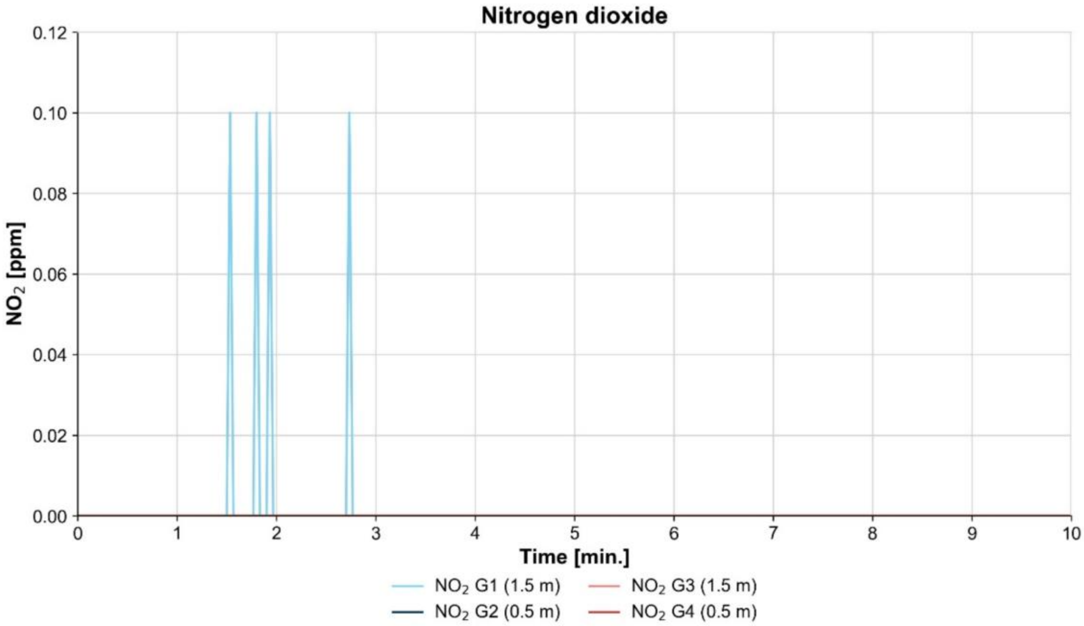
Gases

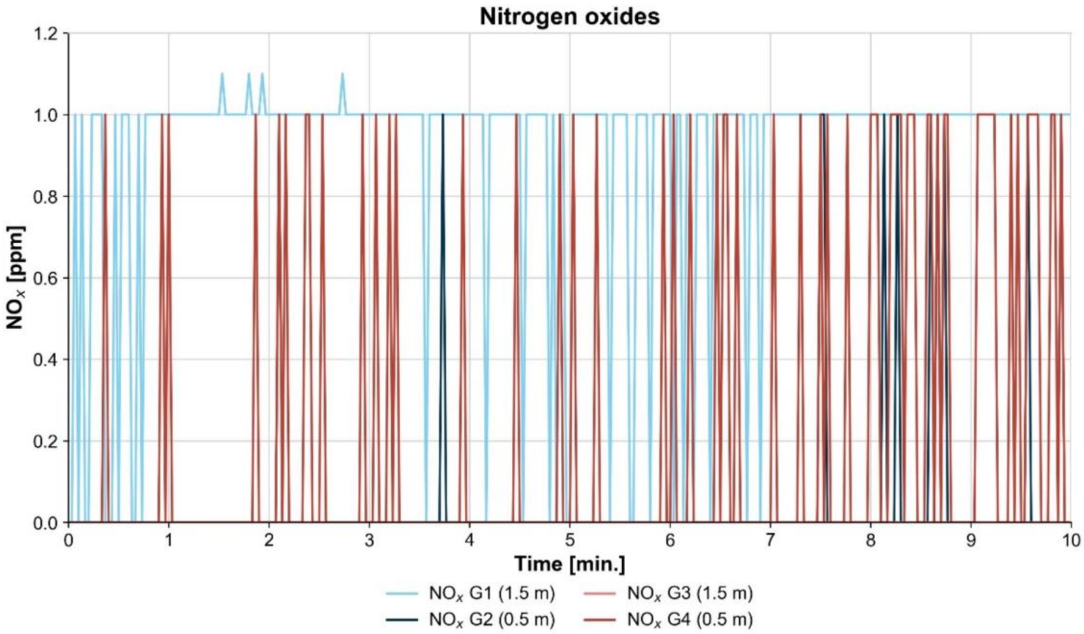

Carbon monoxide
CO [ppm]
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


Oxygen
22
21
20
19
18
O$_2$ [% Vol.]
0
1
2
3
4
5
6
7
8
9
10
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)

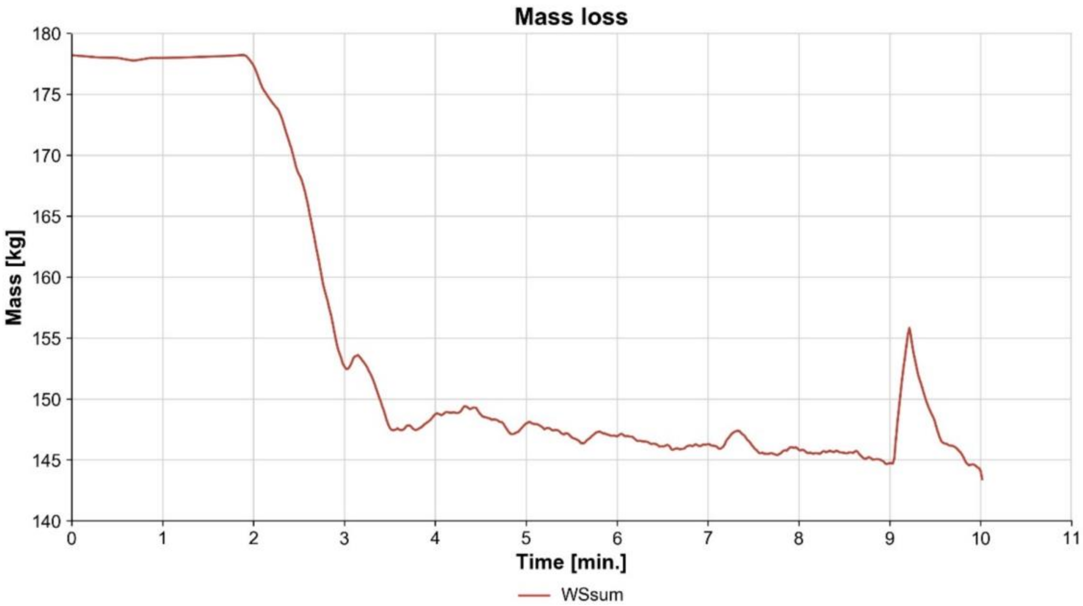

Carbon dioxide
0.30
0.25
0.20
0.15
0.10
0.05
0.00
CO$_2$ [% Vol.]
0
1
2
3
4
5
6
7
8
9
10
Time [min.]
CO$_2$ G1 (1.5 m)
CO$_2$ G3 (1.5 m)
CO$_2$ G2 (0.5 m)
CO$_2$ G4 (0.5 m)


Nitrogen monoxide
NO [ppm]
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)


Nitrogen dioxide
NO_2 [ppm]
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
5
6
7
8
9
10
Time [min.]
NO_2 G1 (1.5 m)
NO_2 G3 (1.5 m)
NO_2 G2 (0.5 m)
NO_2 G4 (0.5 m)

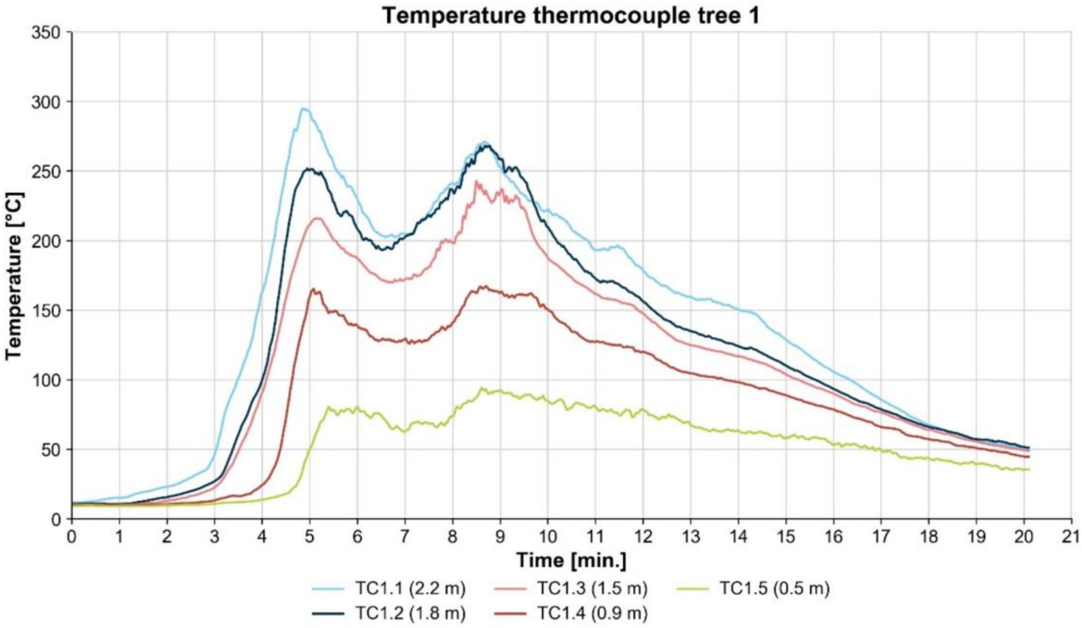

Nitrogen oxides
NOx [ppm]
Time [min.]
NOx G1 (1.5 m)
NOx G3 (1.5 m)
NOx G2 (0.5 m)
NOx G4 (0.5 m)

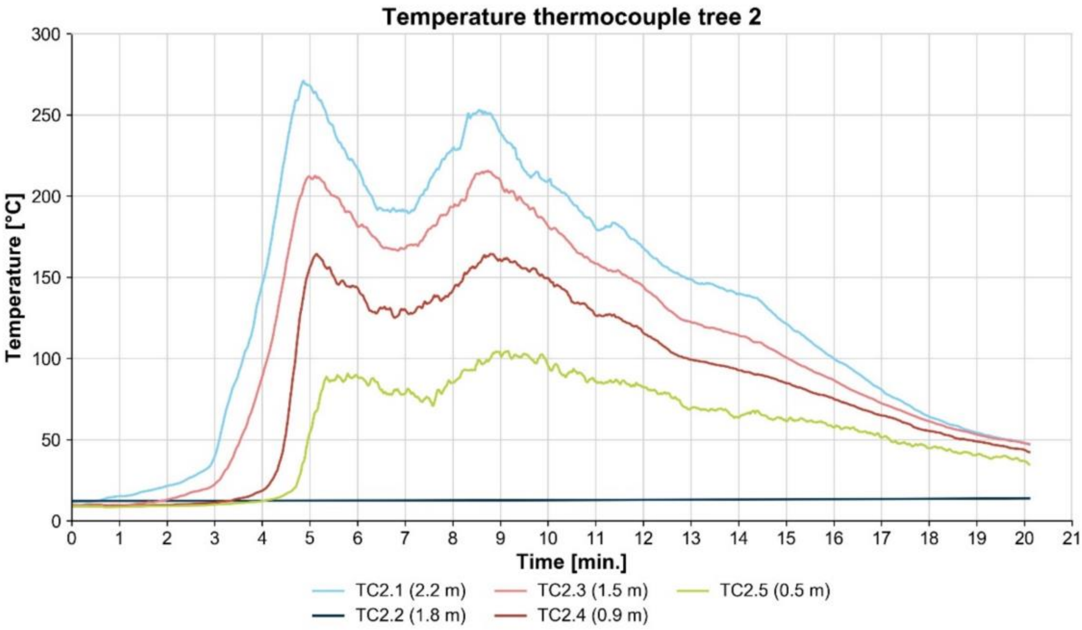
Mass loss


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

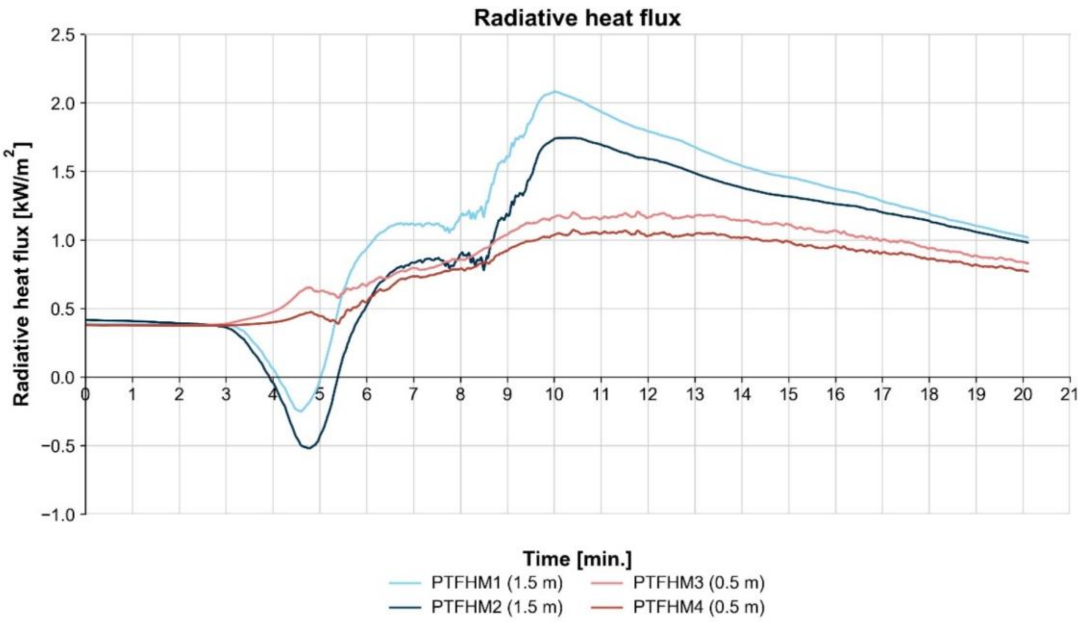
Test 3 conventional mattress crib 5 (door closed)

Heat

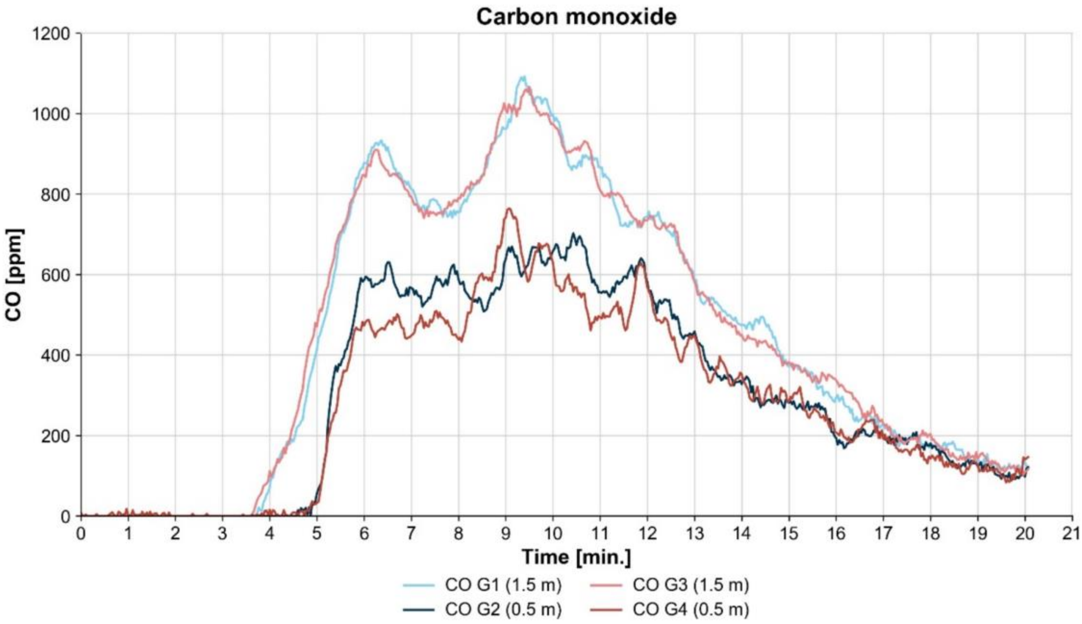


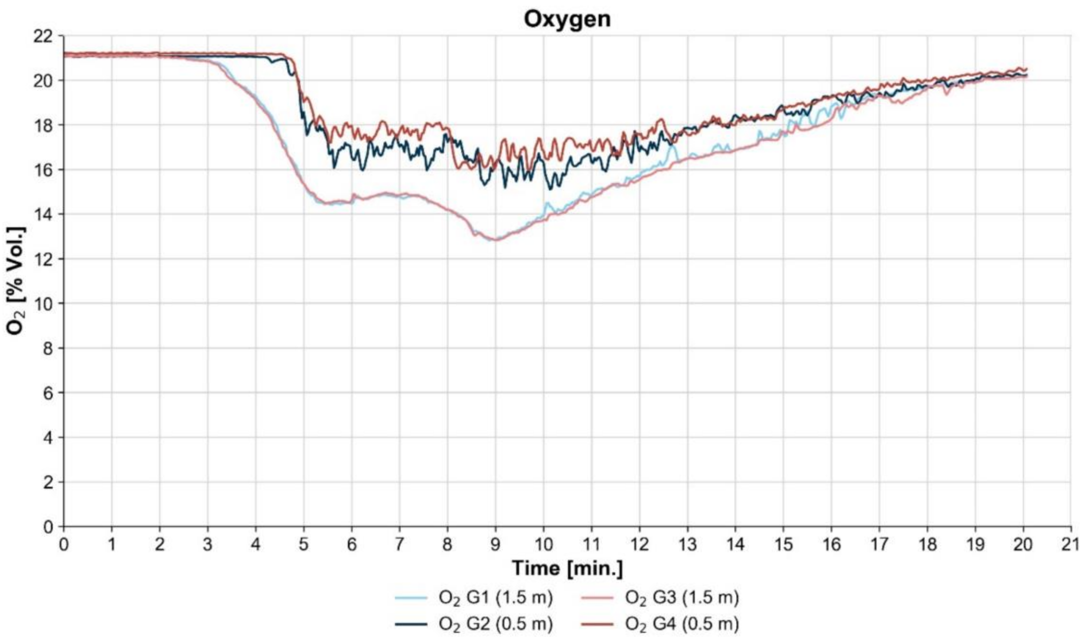


Radiative heat flux

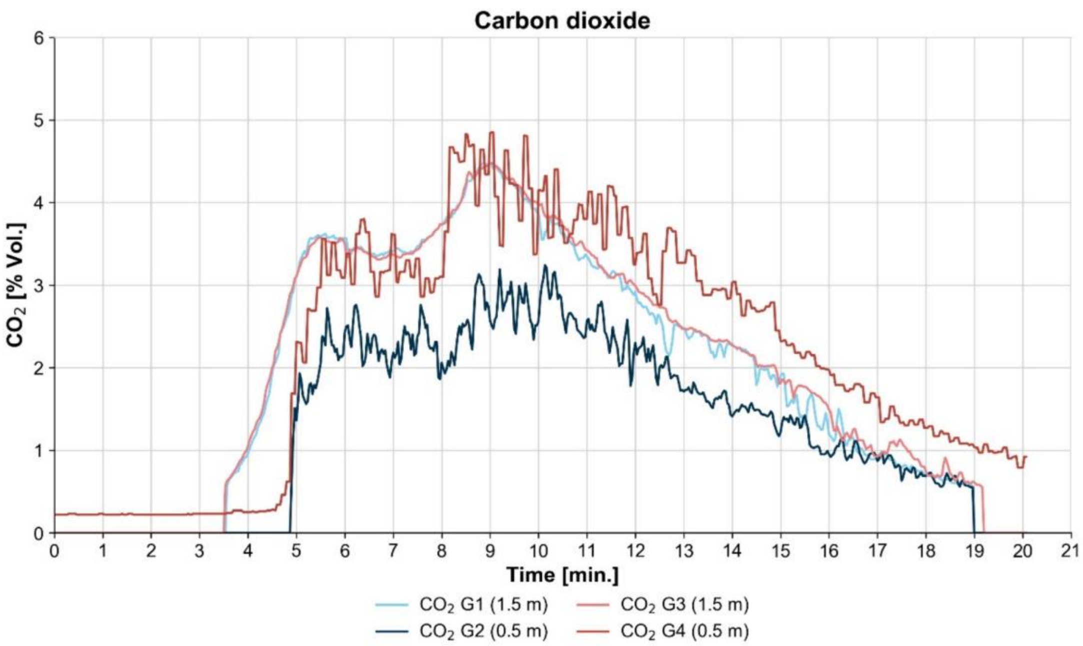

Radiative heat flux
Radiative heat flux [kW/m2]
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

Gases

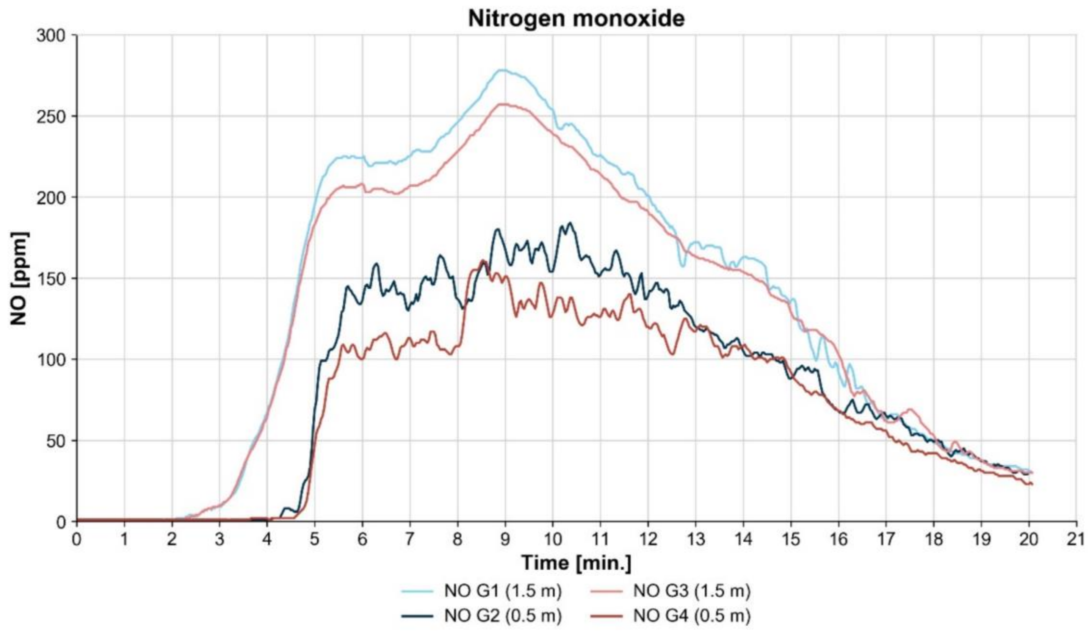

Carbon monoxide
CO [ppm]
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)

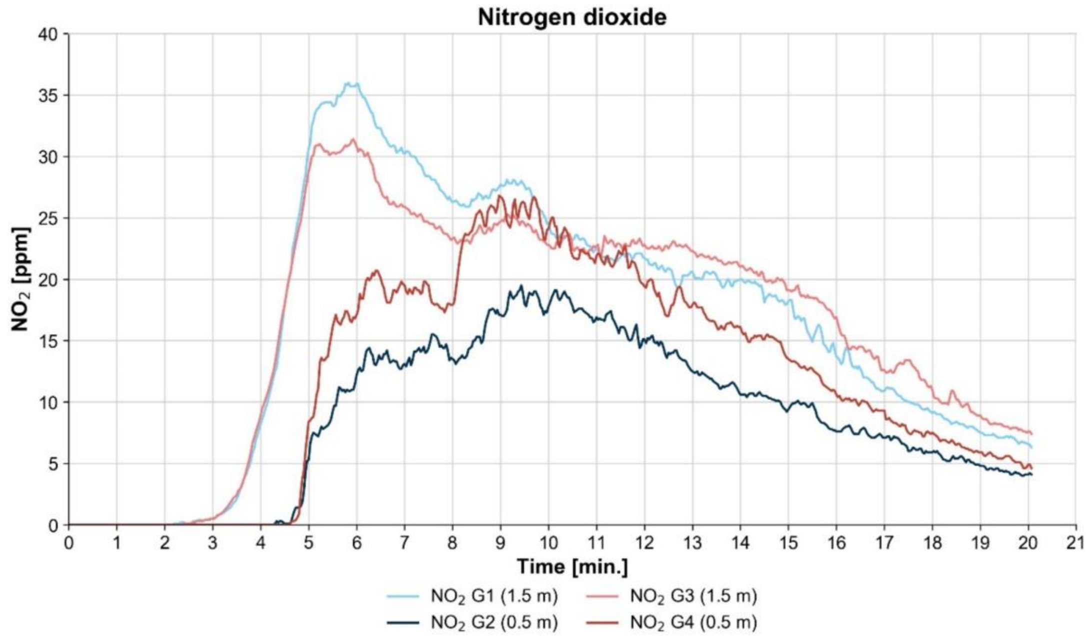


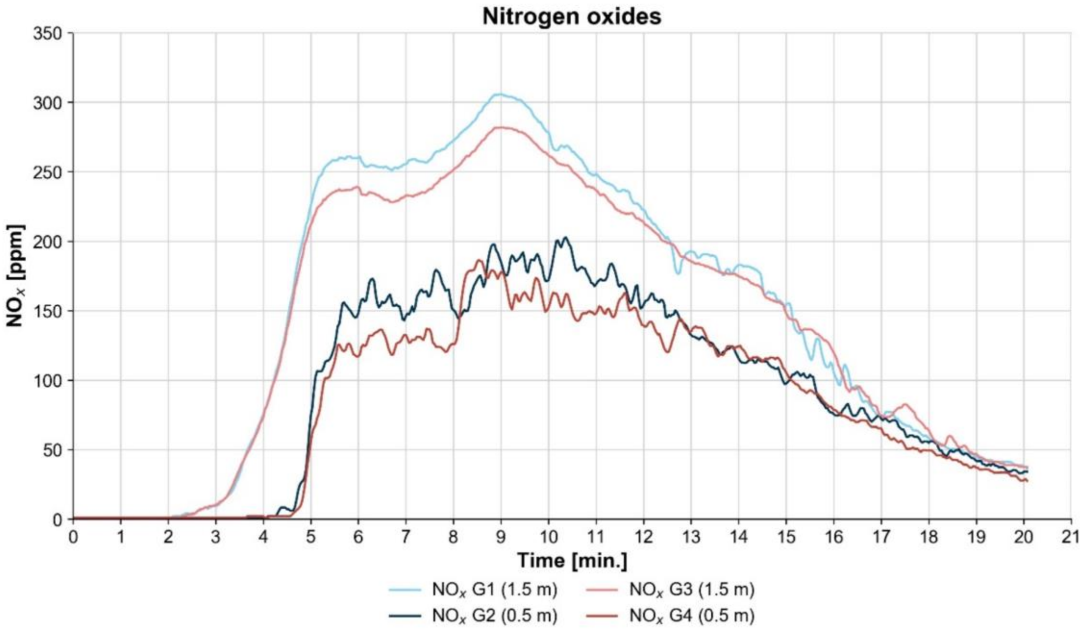
Oxygen
O_2 [% Vol.]
22
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time [min.]
O_2 G1 (1.5 m)
O_2 G3 (1.5 m)
O_2 G2 (0.5 m)
O_2 G4 (0.5 m)



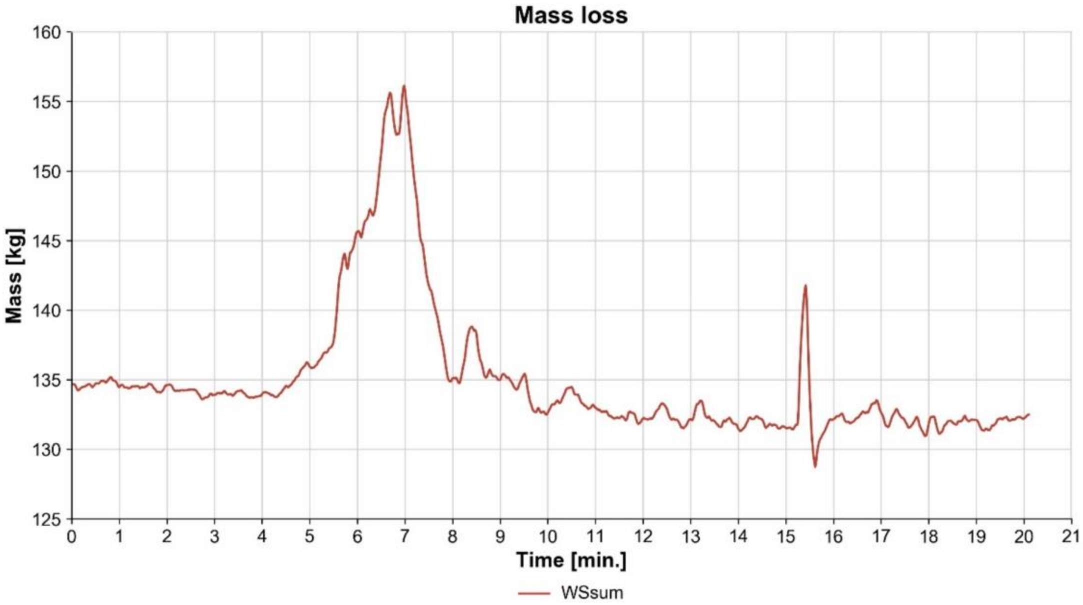
Carbon dioxide
CO_2 [% Vol.]
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Time [min.]
CO_2 G1 (1.5 m)
CO_2 G3 (1.5 m)
CO_2 G2 (0.5 m)
CO_2 G4 (0.5 m)


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


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

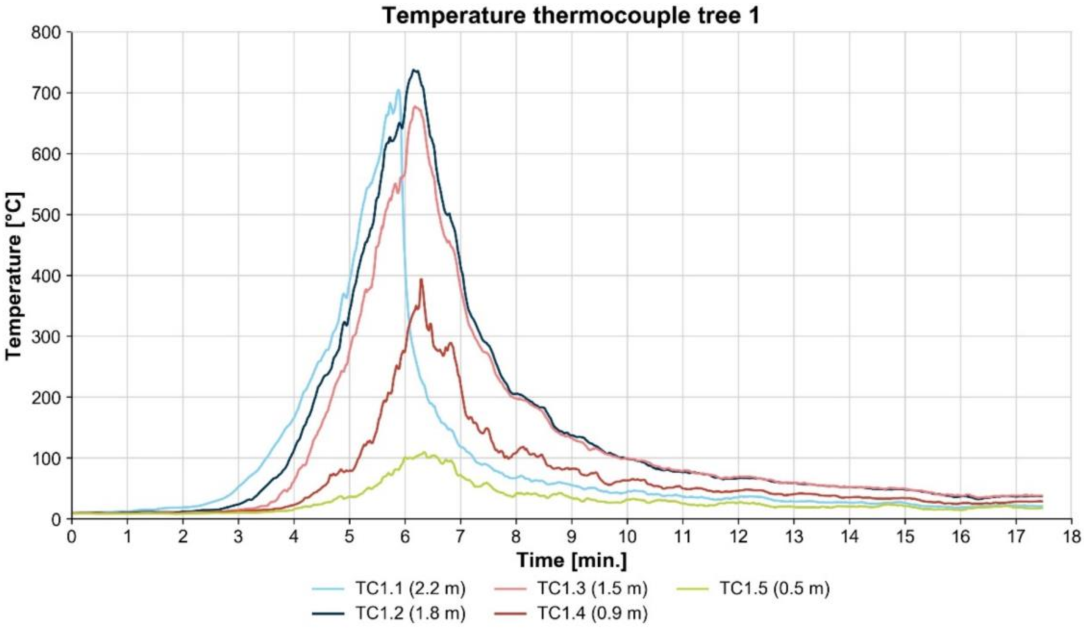

Nitrogen oxides
NOx [ppm]
Time [min.]
NOx G1 (1.5 m)
NOx G3 (1.5 m)
NOx G2 (0.5 m)
NOx G4 (0.5 m)

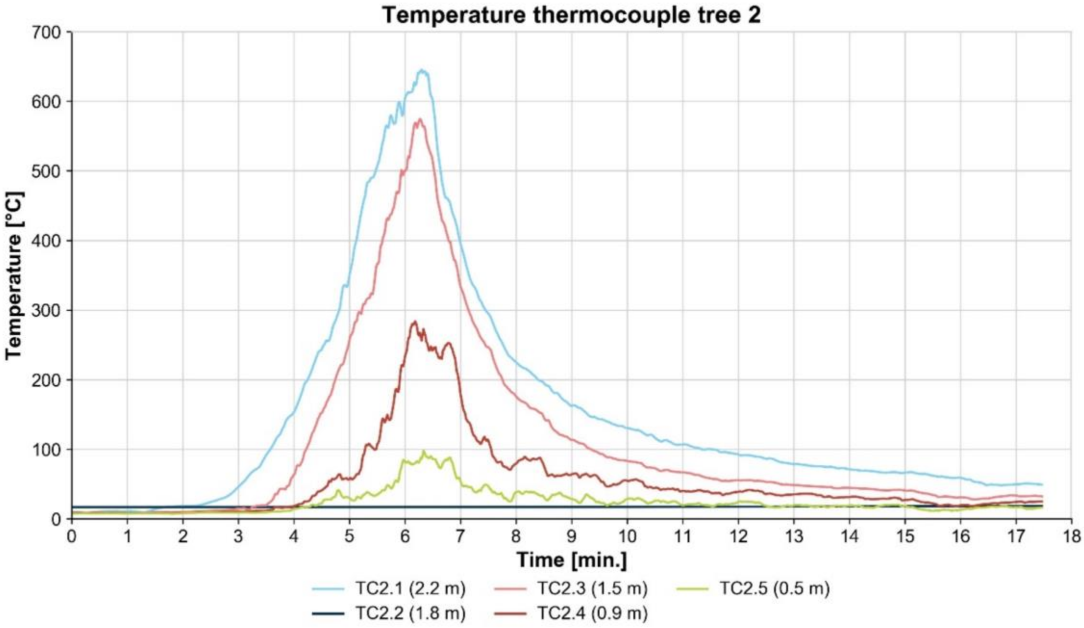
Mass loss


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

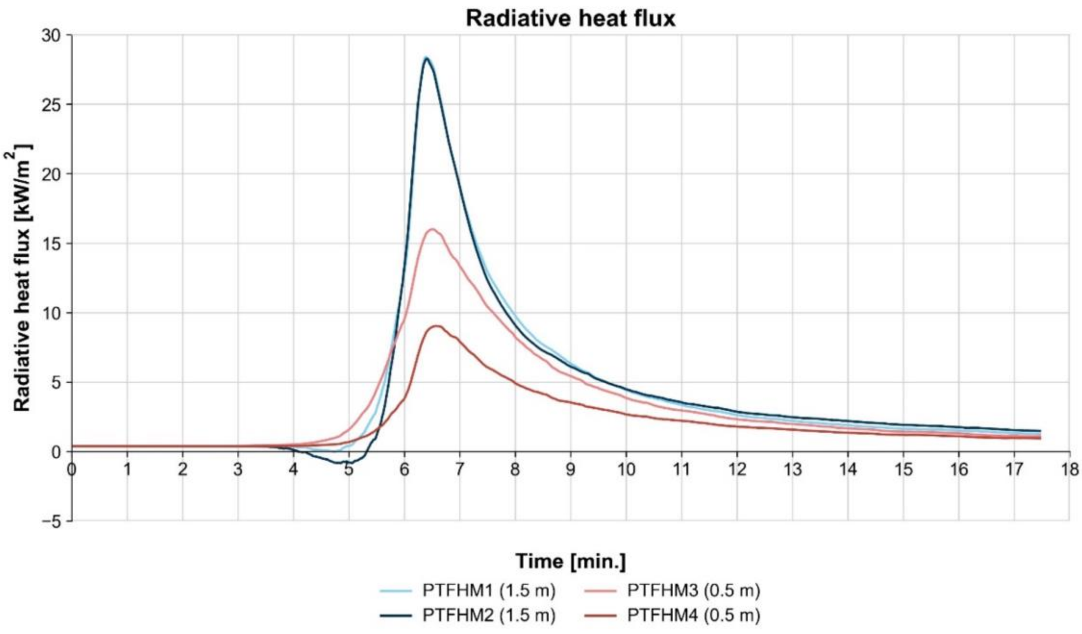
Test 4 conventional mattress crib 5 (door open)

Heat

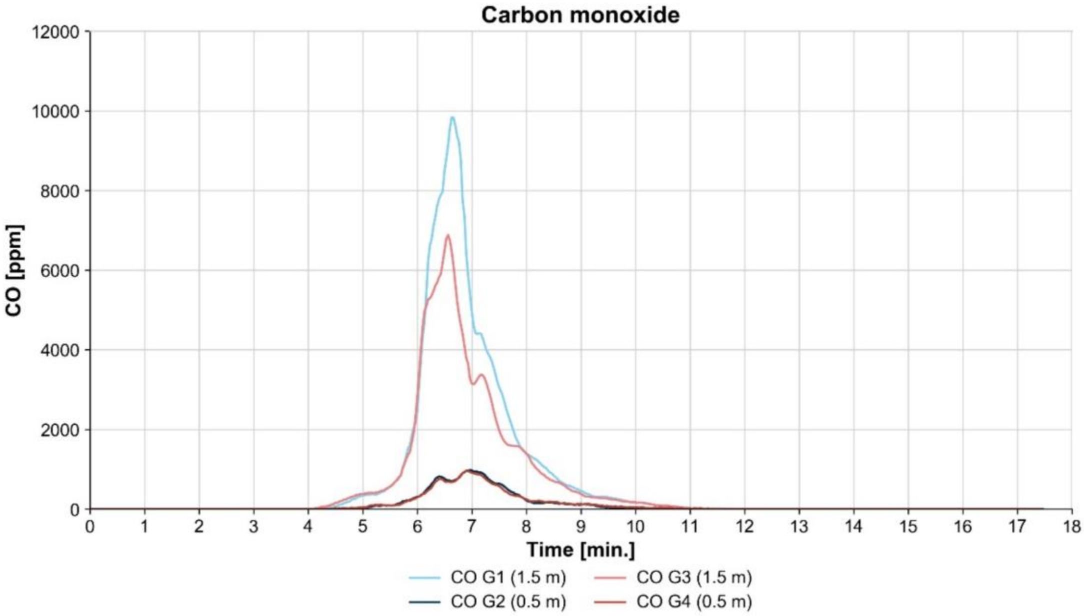


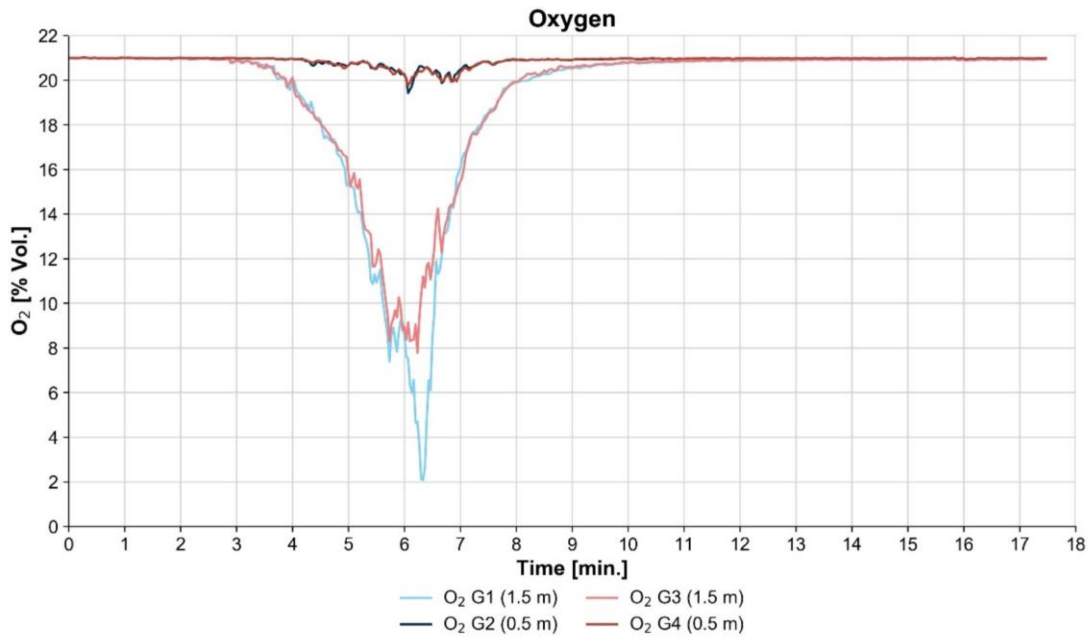


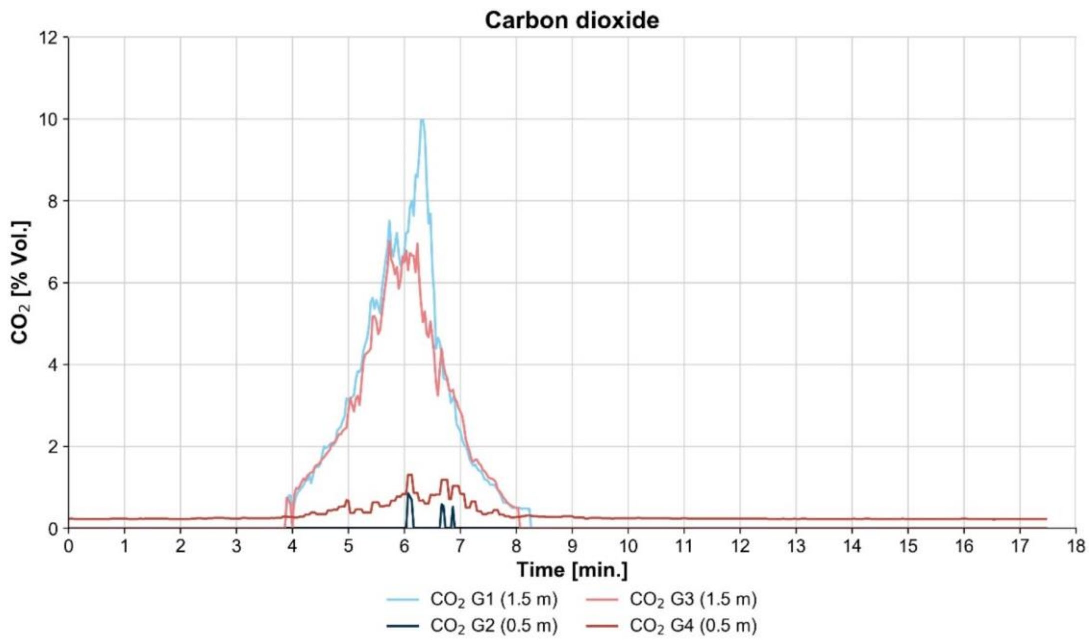
Radiative heat flux

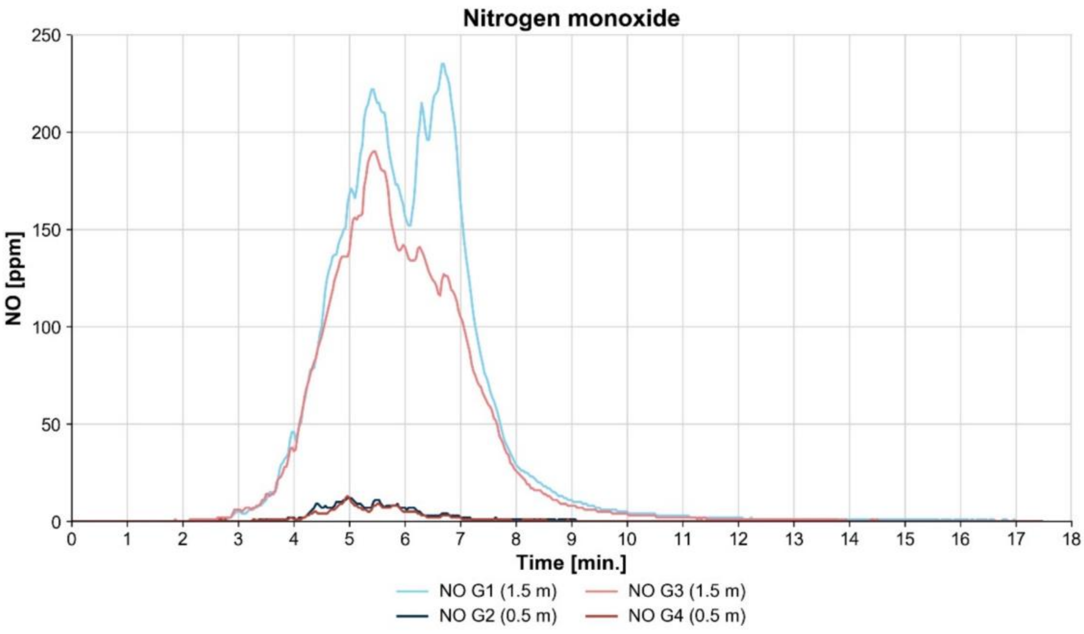

Radiative heat flux
Radiative heat flux [kW/m2]
Time [min.]
PTFHM1 (1.5 m)
PTFHM2 (1.5 m)
PTFHM3 (0.5 m)
PTFHM4 (0.5 m)

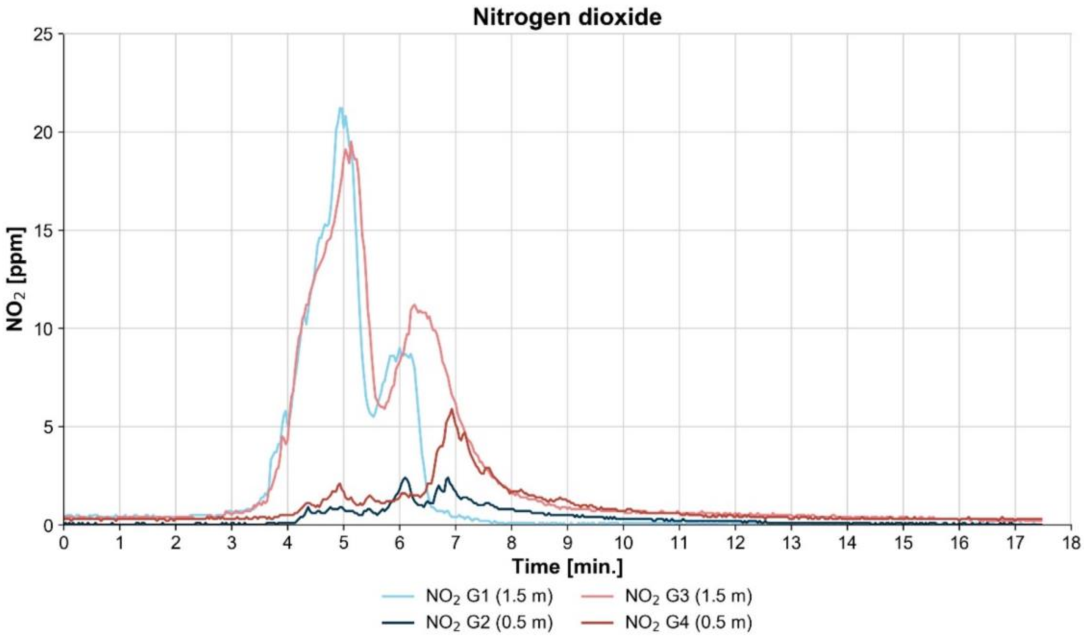
Gases

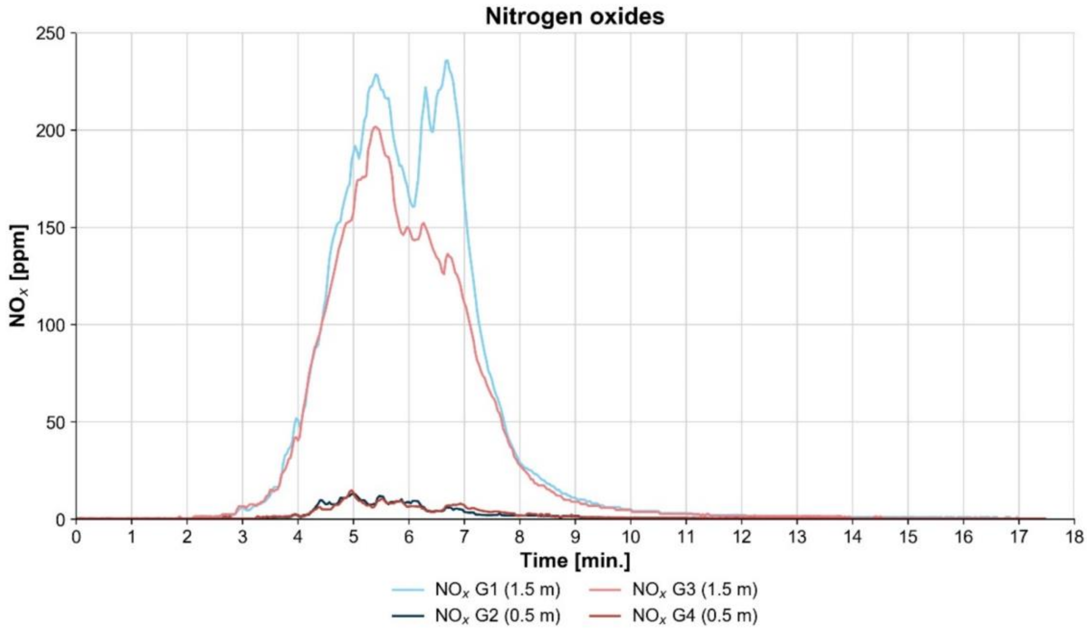

Carbon monoxide
CO [ppm]
Time [min.]
CO G1 (1.5 m)
CO G2 (0.5 m)
CO G3 (1.5 m)
CO G4 (0.5 m)


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)

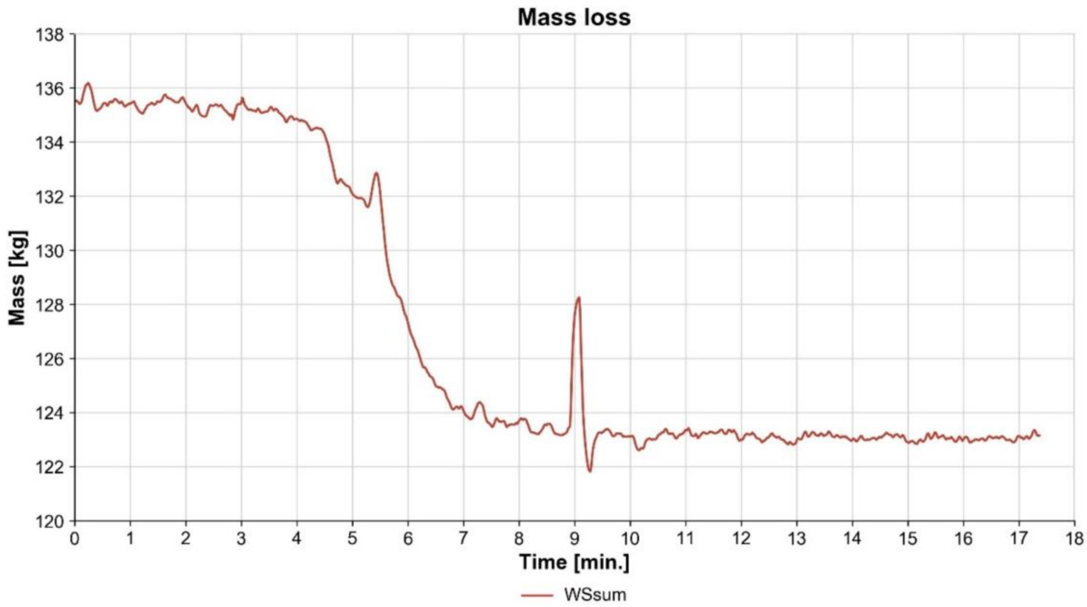

Carbon dioxide
CO_2 [% Vol.]
Time [min.]
CO_2 G1 (1.5 m)
CO_2 G3 (1.5 m)
CO_2 G2 (0.5 m)
CO_2 G4 (0.5 m)


Nitrogen monoxide
NO [ppm]
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Time [min.]
NO G1 (1.5 m)
NO G3 (1.5 m)
NO G2 (0.5 m)
NO G4 (0.5 m)


Nitrogen dioxide
NO_2 [ppm]
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Time [min.]
NO_2 G1 (1.5 m)
NO_2 G3 (1.5 m)
NO_2 G2 (0.5 m)
NO_2 G4 (0.5 m)


Nitrogen oxides
NO_x [ppm]
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
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)

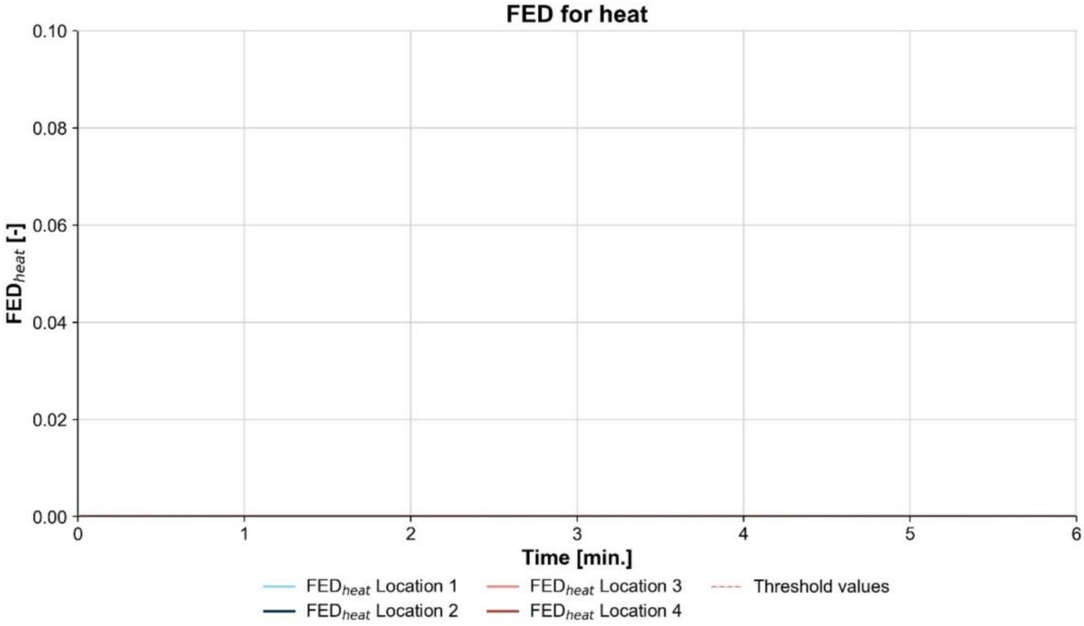
Mass loss


Mass loss
Mass [kg]
138
136
134
132
130
128
126
124
122
120
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Time [min.]
WSsum

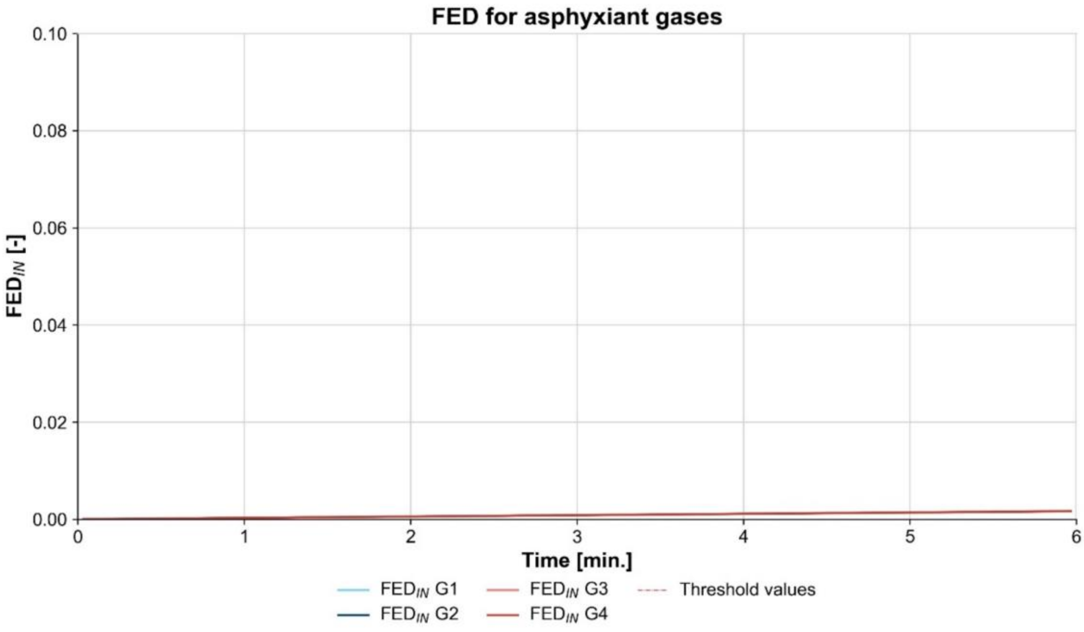
Appendix 3 Overview of the development of the possibility of escape and survivability for the different methods for each measurement location and test.

Test 1a new mattress crib 5 (door closed)

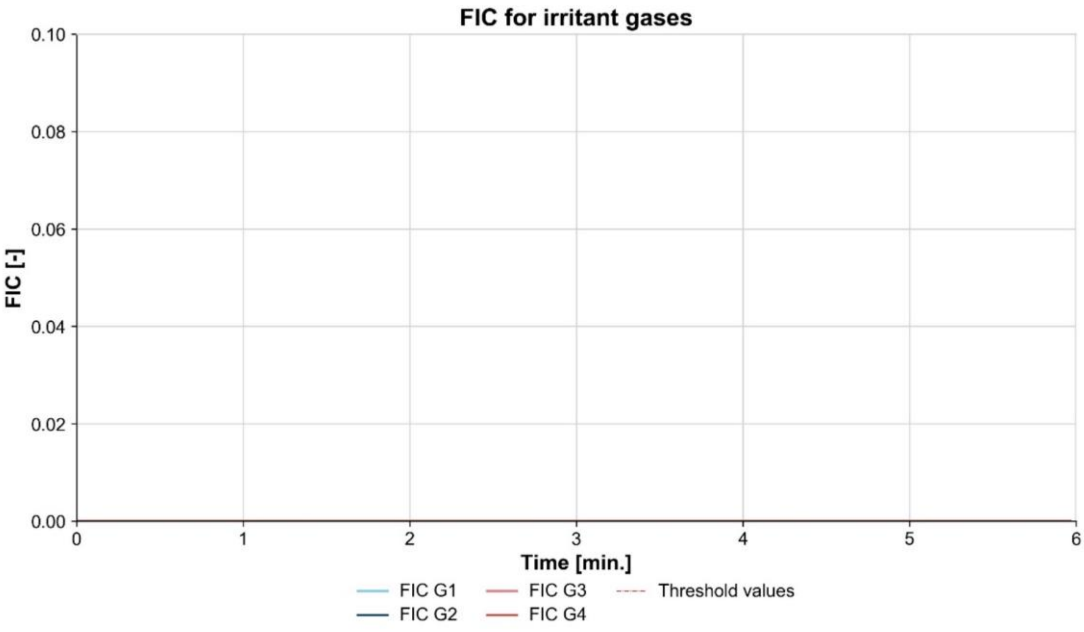
FED for heat



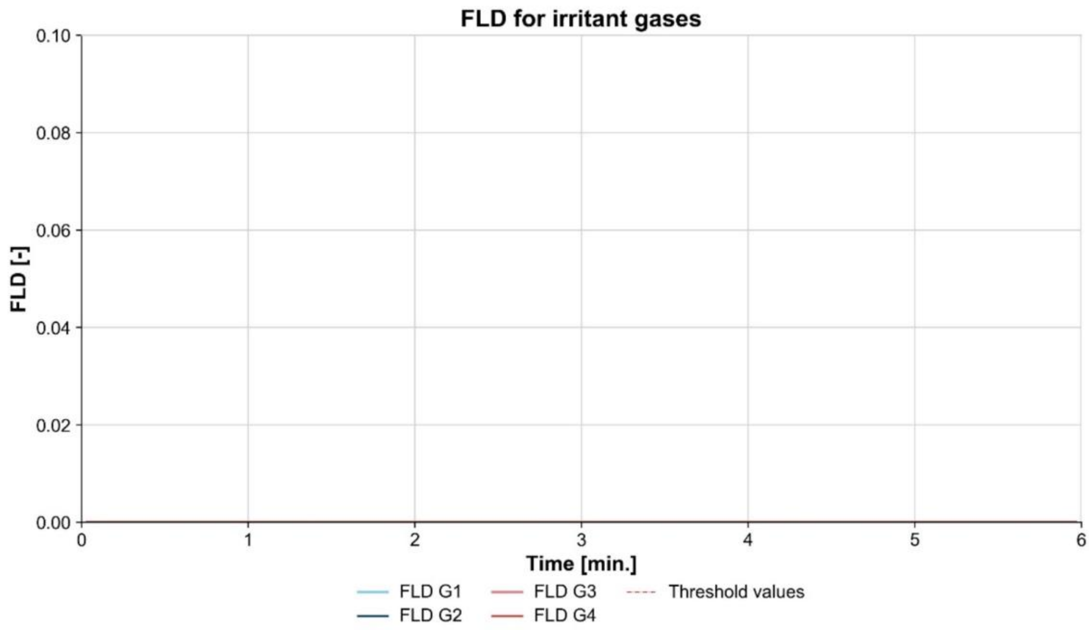
FED for asphyxiant gases



FIC for irritant gases

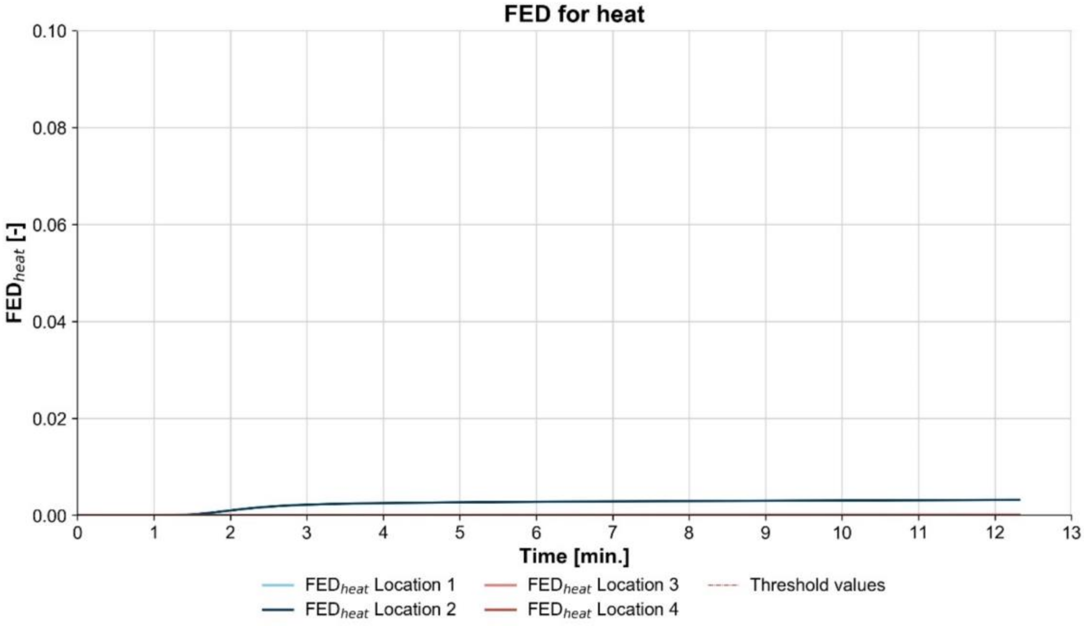


FLD for irritant gases

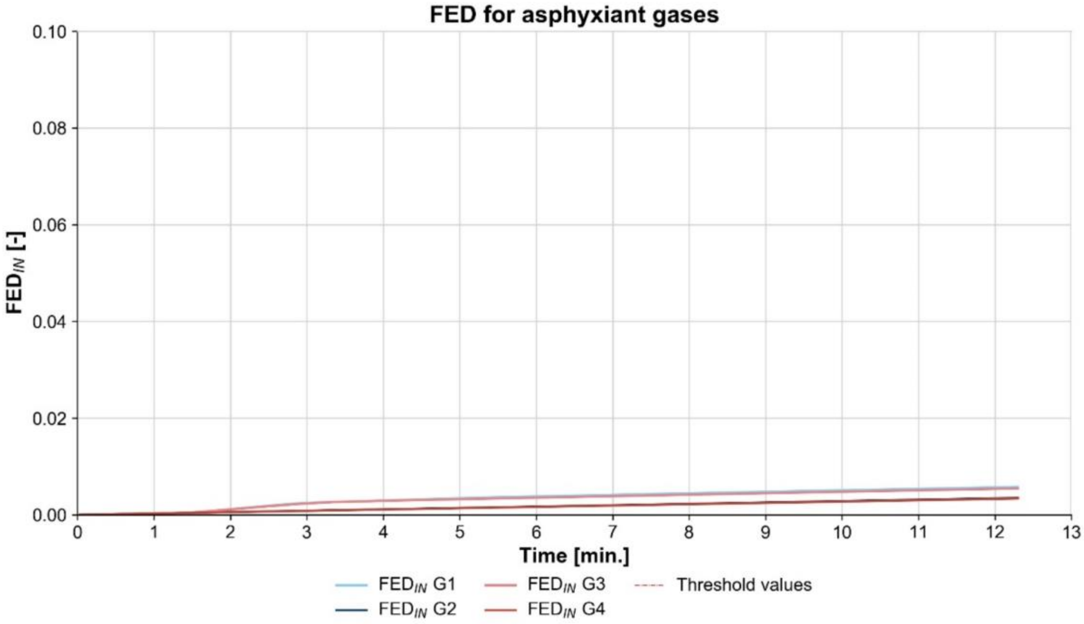

FLD for irritant gases
0.10
0.08
0.06
0.04
0.02
0.00
FLD [-]
0
1
2
3
4
5
6
Time [min.]
FLD G1
FLD G2
FLD G3
FLD G4
Threshold values

Test 1b new mattress isopropanol (door closed)

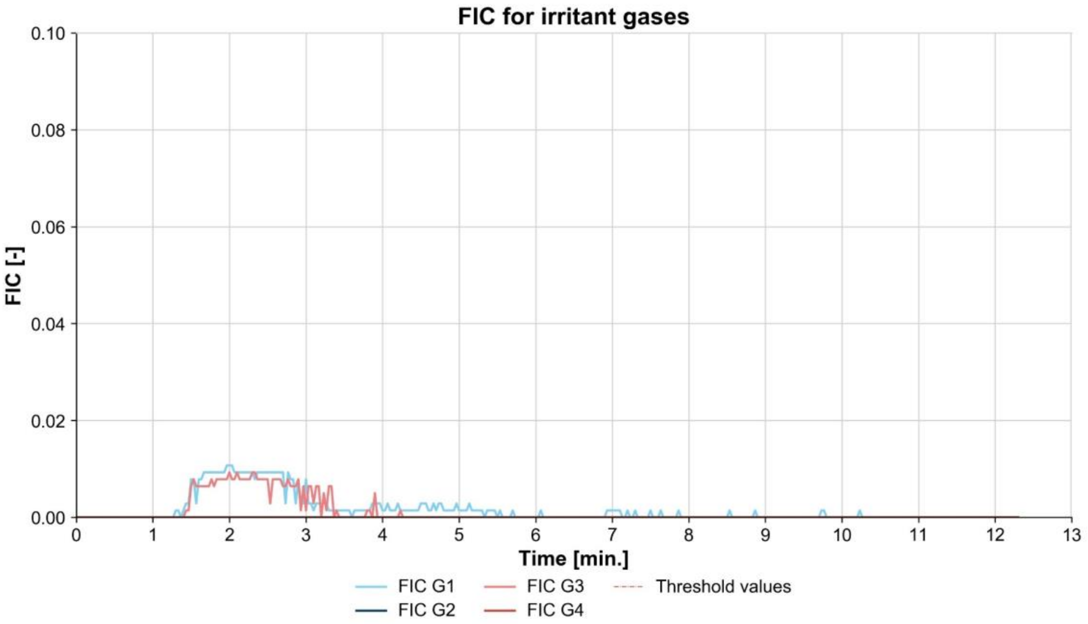
FED for heat



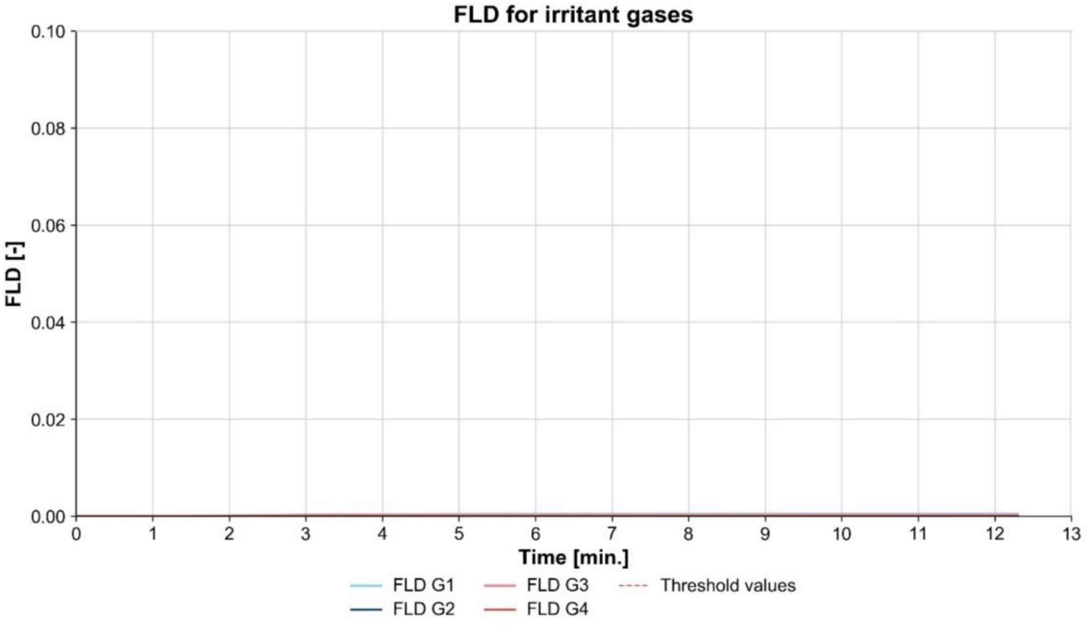
FED for asphyxiant gases



FIC for irritant gases

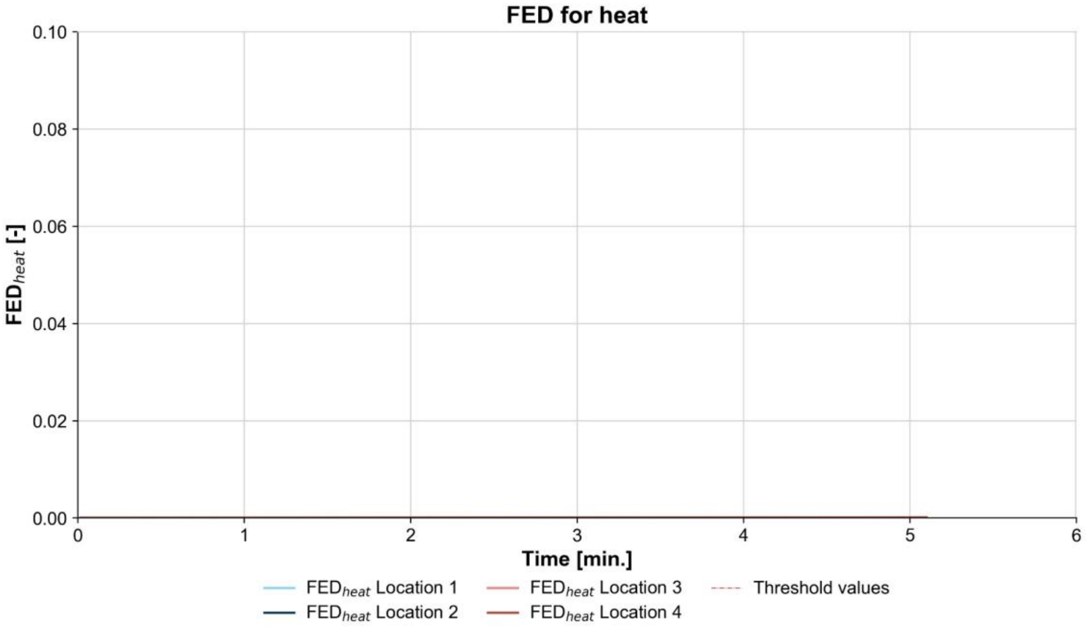


FLD for irritant gases

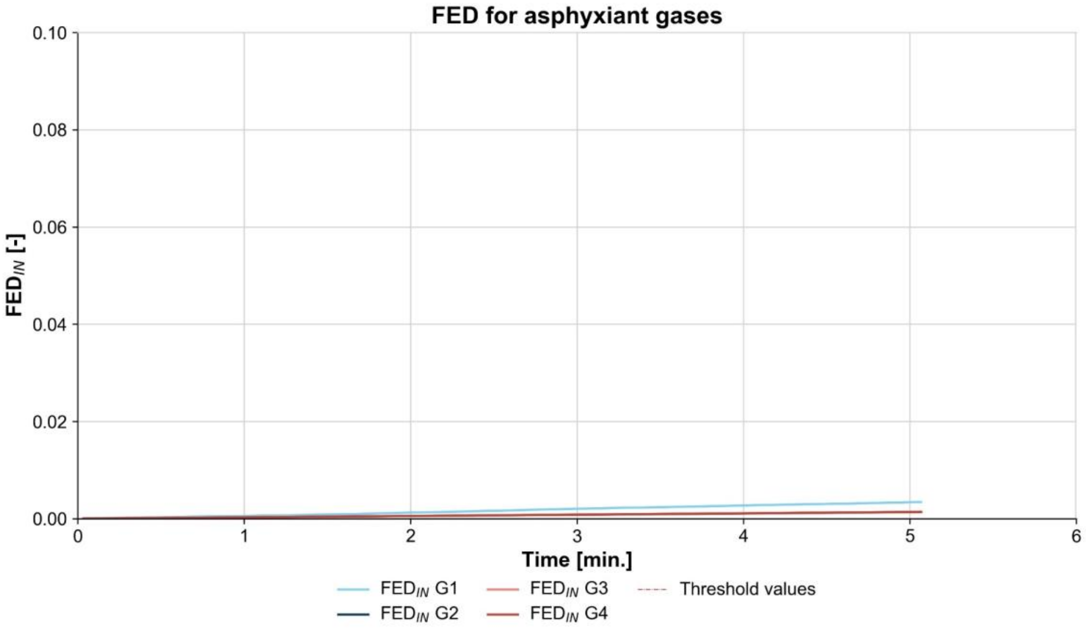


Test 2a new mattress crib 5 (door open)

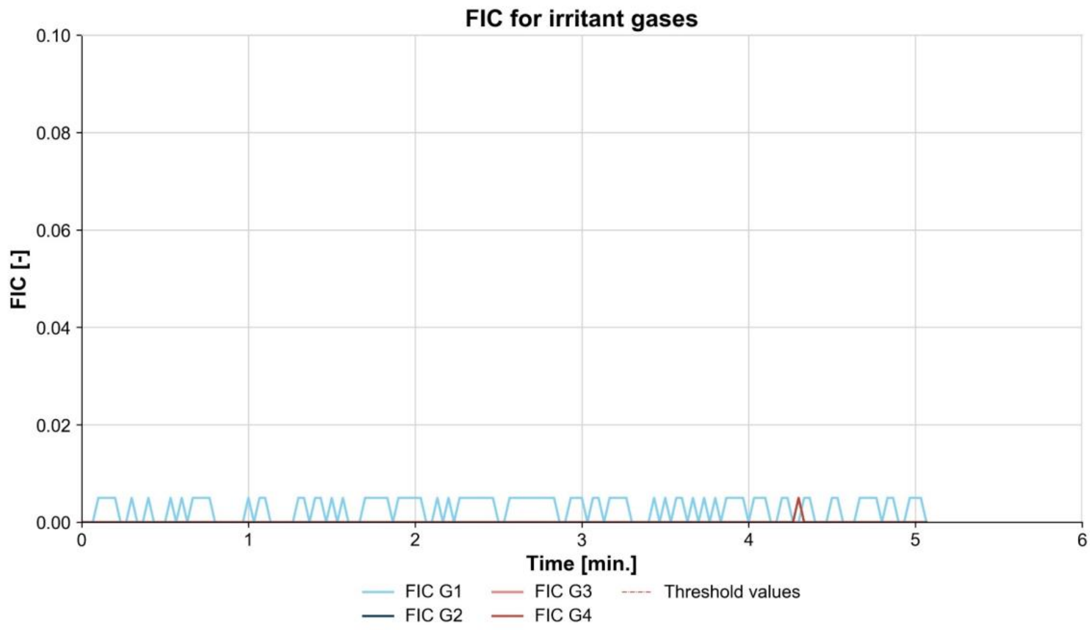
FED for heat



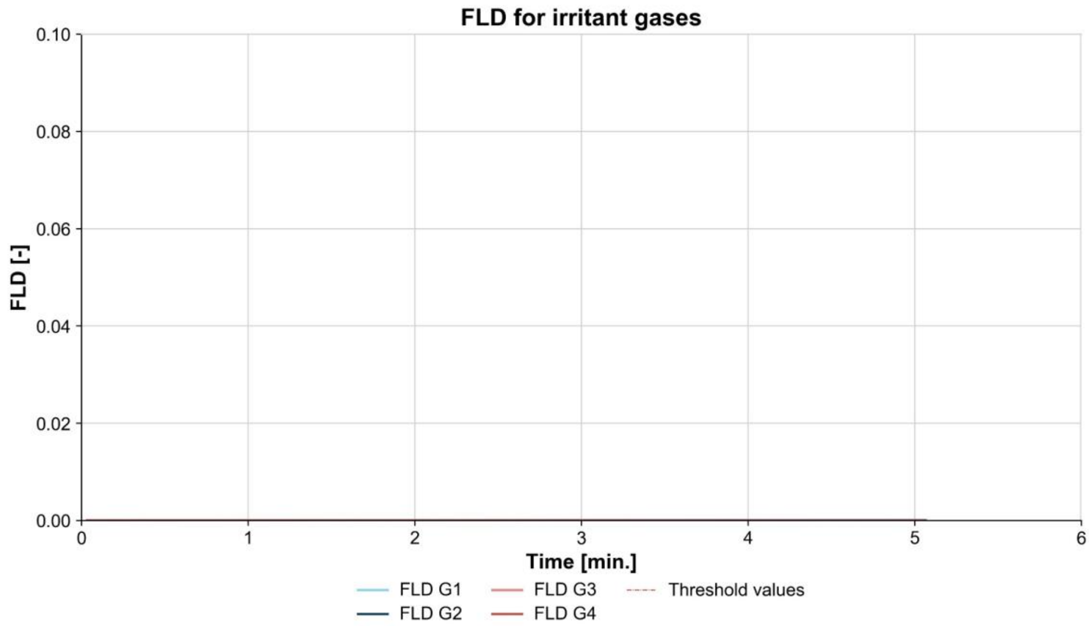
FED for asphyxiant gases



FIC for irritant gases

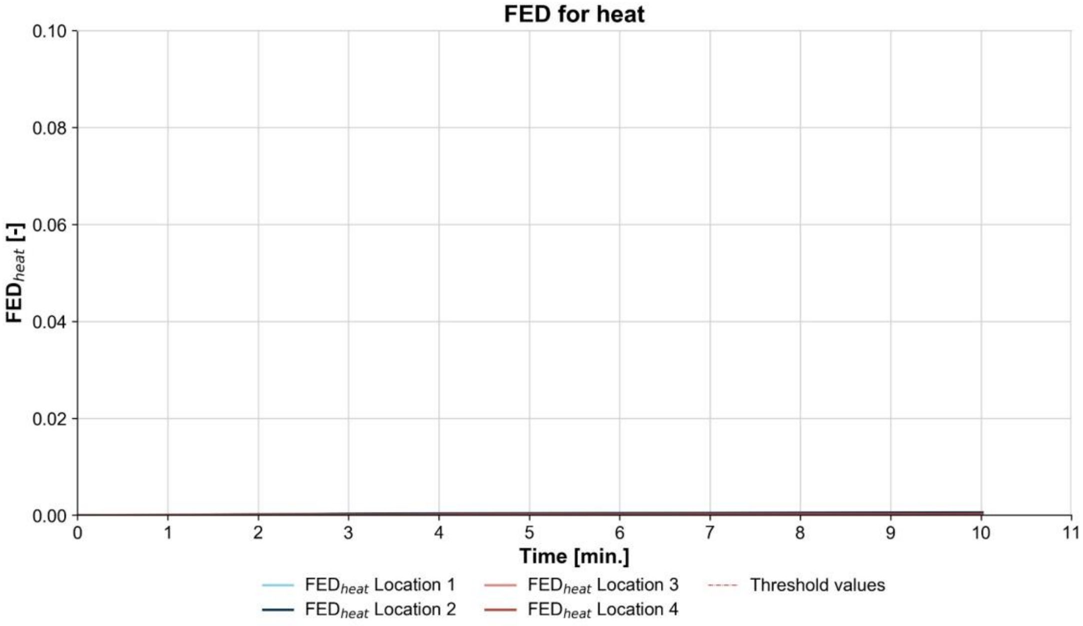


FLD for irritant gases

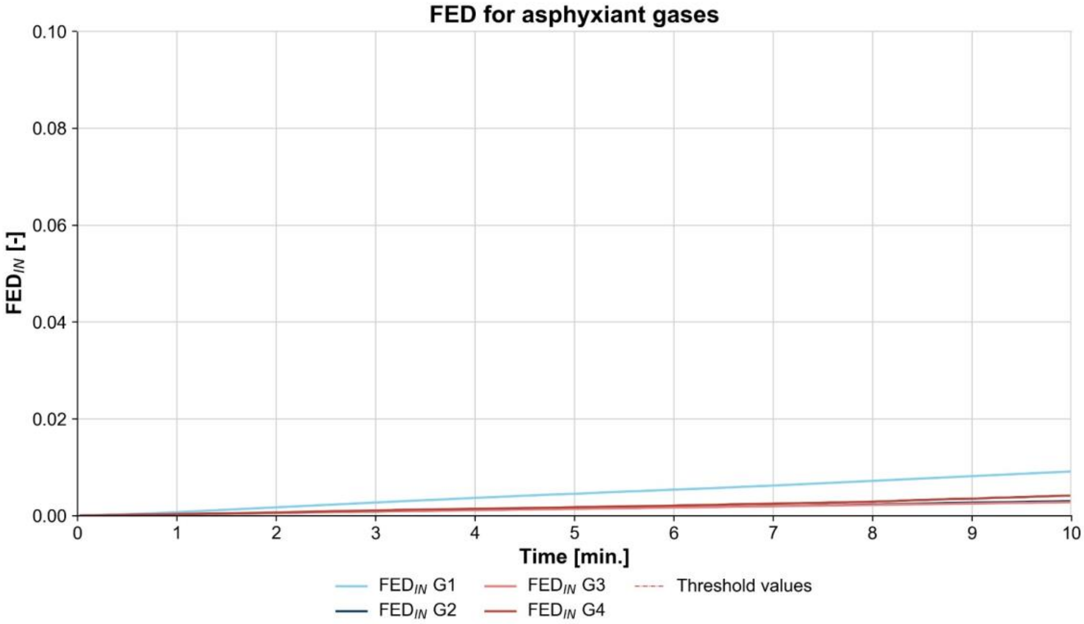


Test 2b new mattress isopropanol (door open)

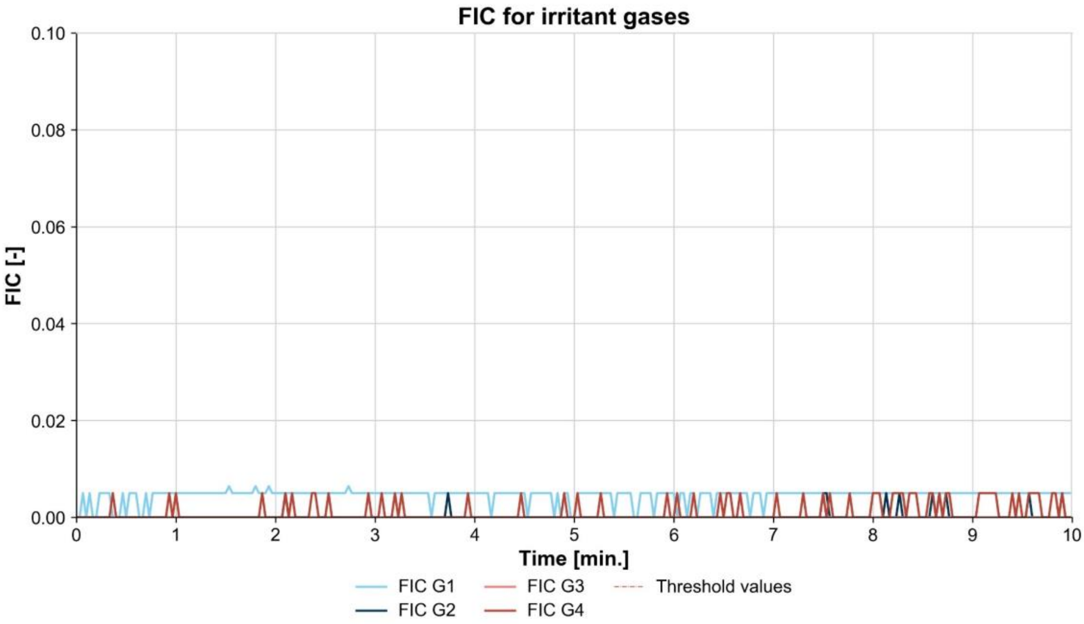
FED for heat



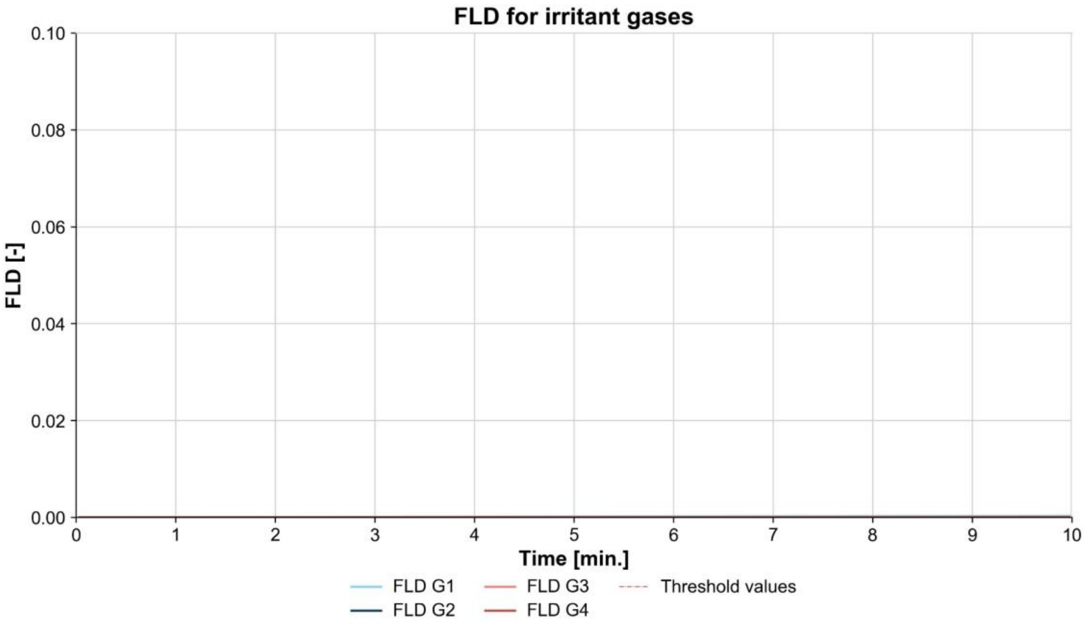
FED for asphyxiant gases



FIC for irritant gases

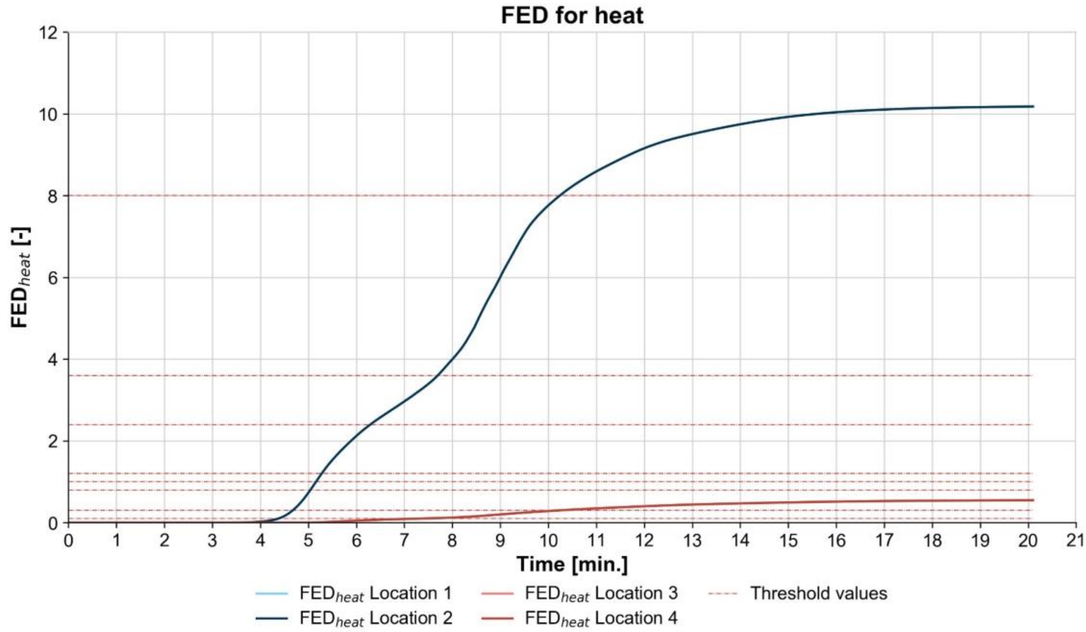


FLD for irritant gases

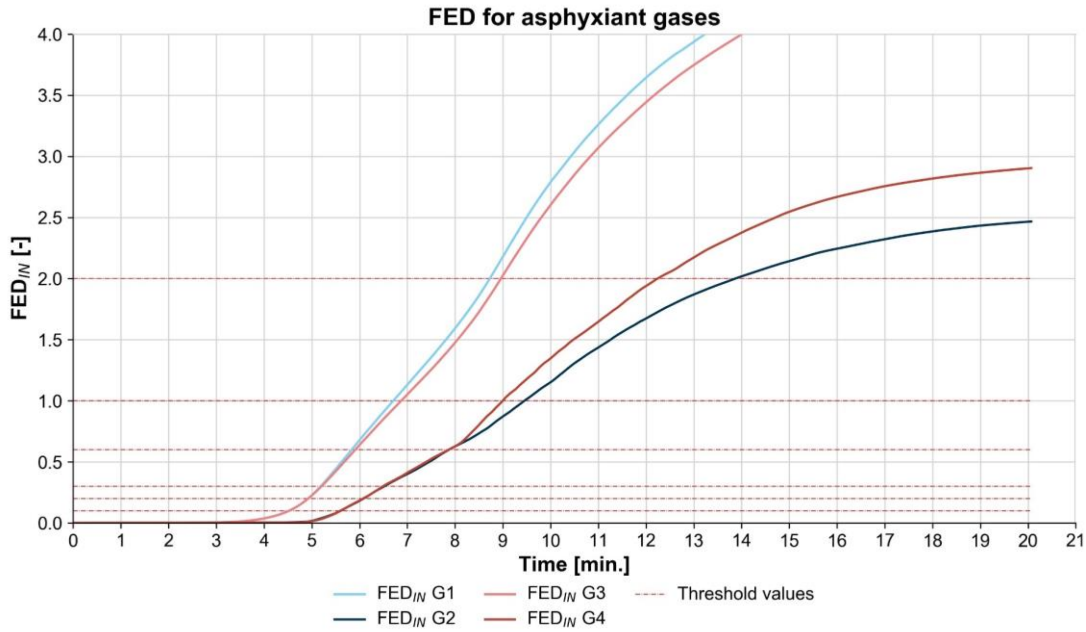


Test 3 conventional mattress crib 5 (door closed)

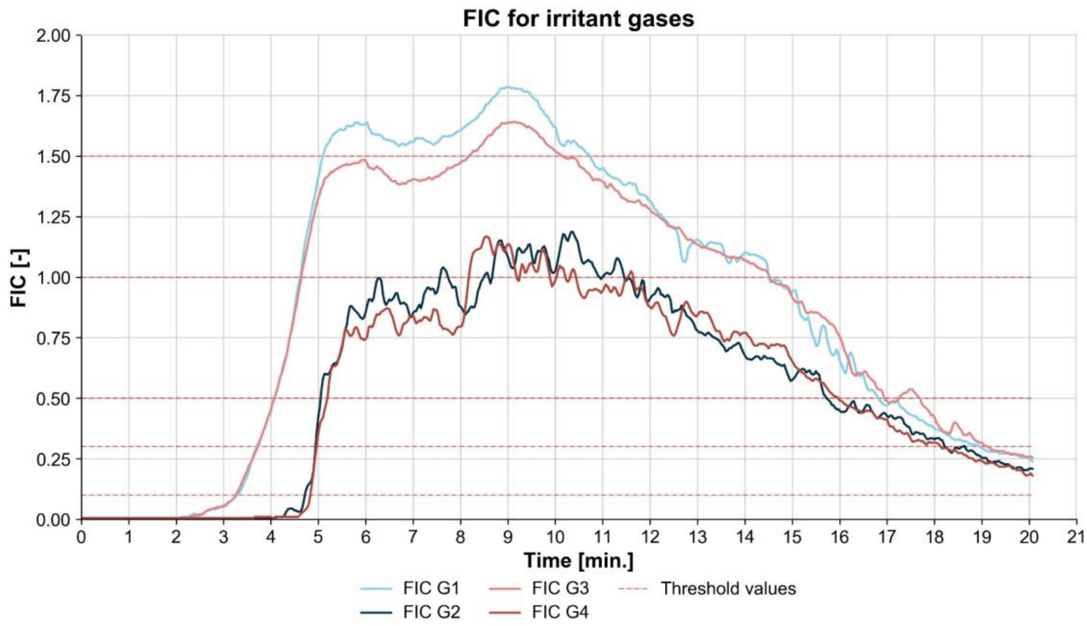
FED for heat



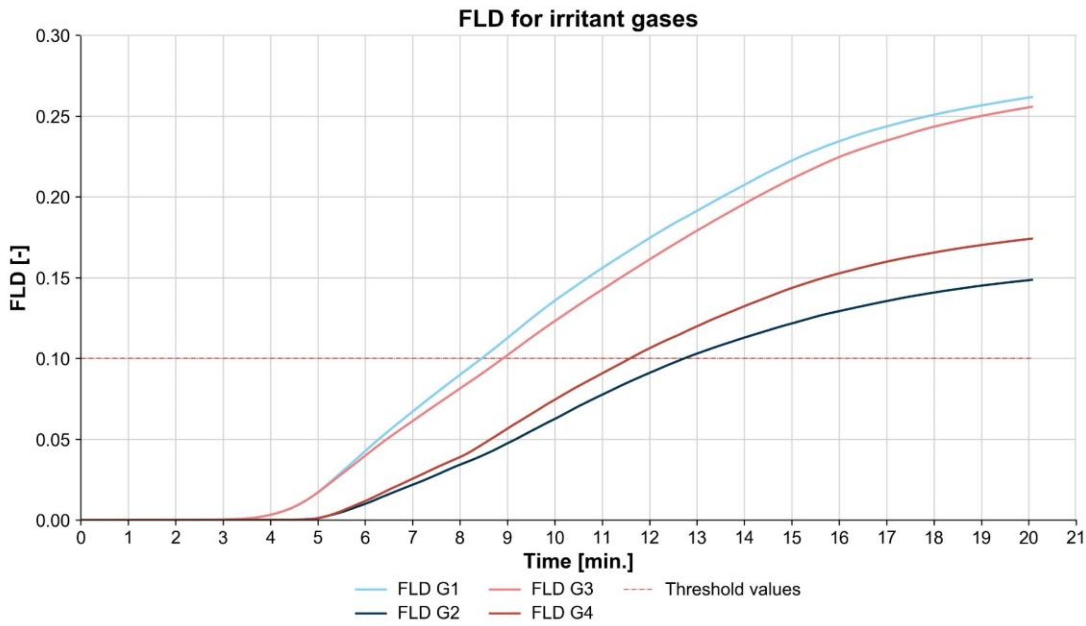
FED for asphyxiant gases



FIC for irritant gases

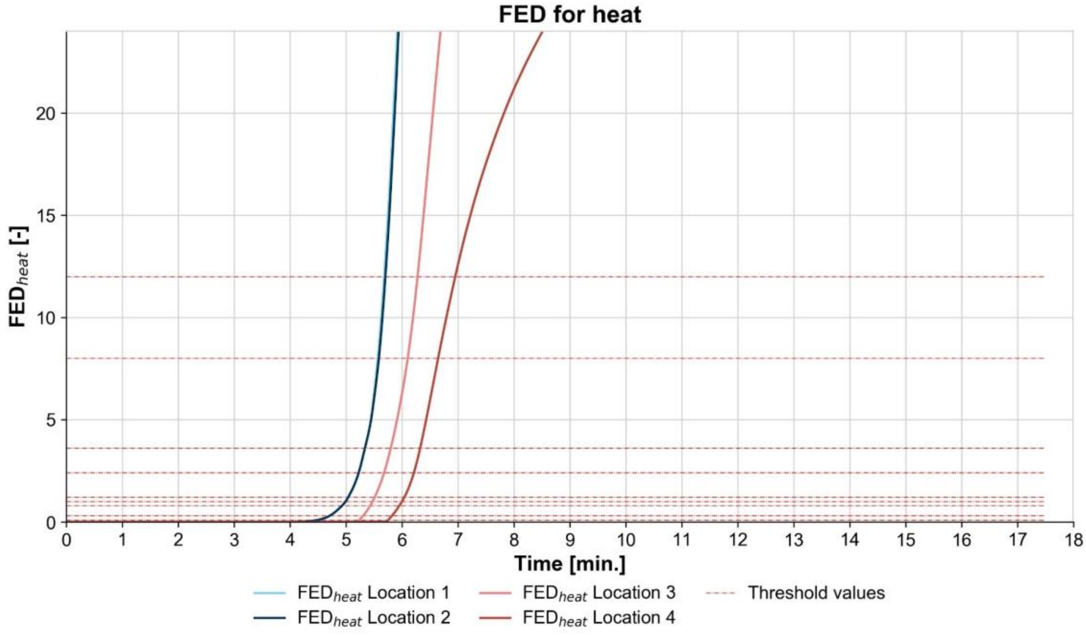


FLD for irritant gases

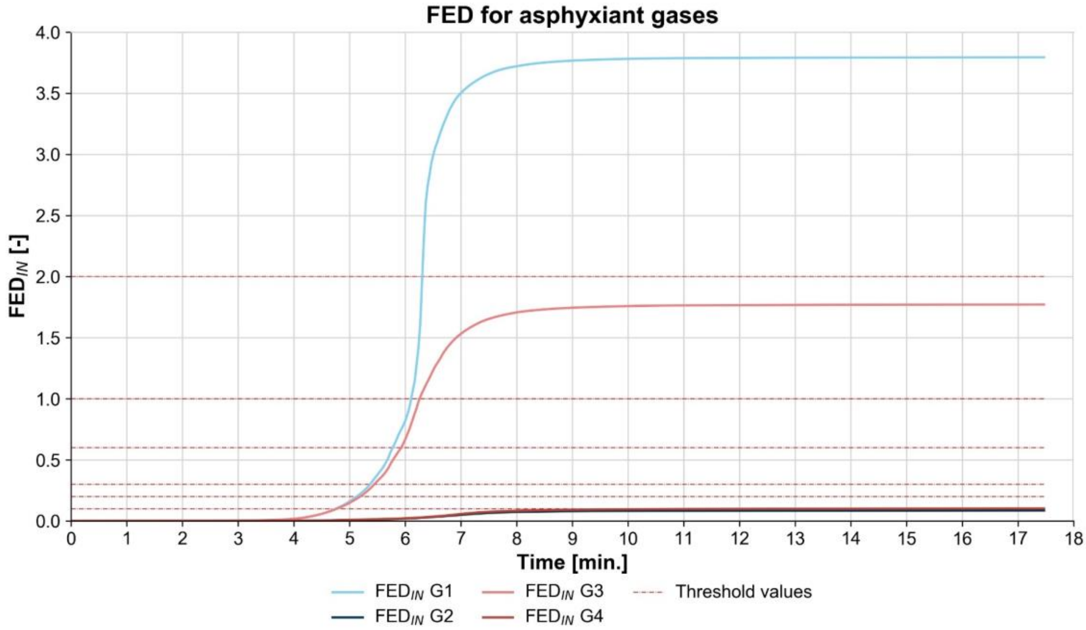


Test 4 conventional mattress crib 5 (door open)

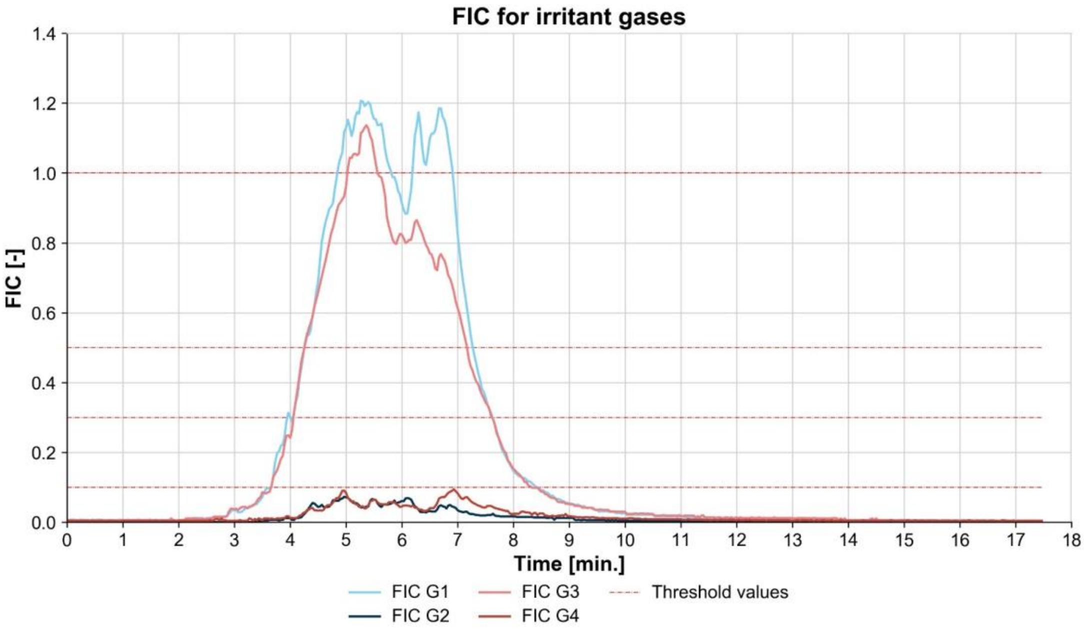
FED for heat



FED for asphyxiant gases



FIC for irritant gases



FLD for irritant gases