Exploring the possibilities of a stay-in-place concept in case of fire

Fire safety engineering

7LS1M0 – BPS MASTERPROJECT A, RESEARCH

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07-10-2022

MASTER PROJECT

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Table of Contents

List of figures

List of tables

1 Introduction

1.1 Problem definition

People grow older every day, in comparison to 30 to 40 years ago, on average people get 5 to 7 years older (CBS, 2020a). As shown in Figure 1-1 and in Table 1-1, the population of people older than 80 years will increase with 151% in the next 50 years. Today there are 1.3 million people older than 75 years, in 2030 that will be 2.1 million people and in 2040, 2.5 million people will be older than 75 years. 92% of people older than 75 years are living on their own and 67% of the people older than 90 still live on their own. Almost a quarter of the people older than 75 uses help and care at home (Ministerie van Volksgezondheid Welzijn en Sport, 2015). According to the building code these people are self-reliant. However these people may not be self-reliant in case of emergency, for instance a fire.

Smoke and/or the fire can be lethal. Not only for the elderly but also for younger people, for instance in the case of the fire on new year's eve in Arnhem. A father and his son died due to exposure to smoke in the escape route, generated by the fire. Instead of evacuation, a new concept can solve these problems. The stay-in-place concept can be a solution.

In order to implement a stay-in-place concept, research needs to be conducted. This research is described in this document.

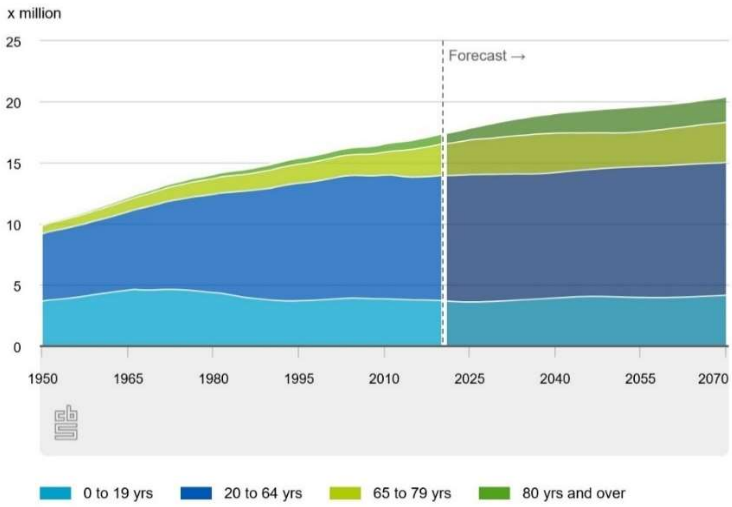

Figure 1-1. Population prediction by age (CBS, 2020b).

Table 1-1. Predicted population increase for the next 50 years (CBS, 2020a).

Age (years)	**Population 2020 [million]**	**Predicted population 2070 [million]**	**Population increase [million]**	**Population increase [%]**
0 to 19	3.78	4.22	+0.44	12
20 to 64	10.24	10.87	+0.63	6
65 to 79	2.57	3.28	+0.71	28
80 and over	0.82	2.06	+1.24	151

1.1.1 Problem field

Is it possible to create a fire safety concept for a building, without evacuating the building occupants? Then escape routes are no longer necessary. What are the consequences to the airtightness of the internal and external separation constructions?

In case of fire the personal safety of building occupants is guaranteed by the escape routes. When escape routes are blocked or cannot be used by the building occupants, personal safety has to be guaranteed in another way. By creating very reliable fire and smoke resistant separation constructions between compartments in a building a 'stay-in-place' concept might be a solution. What is the reliability of smoke resistant separation constructions in a stay-in-place concept?

1.2 Research objective

The research objective is to gain insight in the possibility of using a stay-in-place concept in (new) multi-story (apartment)buildings and what effects need to be taken into account when this concept is used.

1.3 Research question

To what extend can a stay-in-place concept be used in multi-storey multi-compartments residential buildings, nursery homes and hospitals?

1. How does the stay-in-place concept relate to the Dutch national building code; construction environment decree (2021)?
2. For which buildings/building users is this concept applicable?
3. What should be the reliability of the load bearing structure/fire compartmentation/sub-compartmentation for a stay-in-place concept?
4. Is it possible to add redundancy to a stay-in-place concept?

1.4 Research method

In order to answer the formulated research question a literature review, simulation, and experiments would be suitable methods. However due to the limited available time (10 ECTS) of the master project, experiments will not be conducted during this master project. Based on a case study simulations can be conducted to determine the available safe time in escape routes and adjacent compartments. During the available safe time the conditions are acceptable for personal safety of the building occupants. In order to build a suitable simulation model a (literature) study is necessary for the following aspects:

- A literature review in to the new building code. Questions like, " what is the reliability of a fire compartment/sub compartments/smoke compartments?" need to be answered.
- A literature review in to smoke. Questions like, "When does smoke become toxic(acceptable values or doses for preventing health damage or lethality?)", "When does smoke cause invisibility?", need to be answered.
- The behaviour of the fire and smoke in an air tight building. Questions like, "How will the smoke be spread through the building?", "How will the fire develop in an air tight building?", need to be answered. Tightness of external constructions in comparison to internal constructions.
- A short comparison of software tools to find out which software tool is most suitable to use for the described scenario.

  - Bases on previous research C-fast shows a similarity with an already developed fire and less so with a developing fire. Brisk shows similarity with the development of a fire and deviates from the experiments in the case of a developed fire.
- Airtightness of separations constructions, both external and internal.
- What kind of fire safety installations and devices can be applied to increase the safety level in both and evacuation concept and a stay-in-place concept?

The simulations will be based on a case study. The design of the building will be a new 5 story apartment building. The building will be built in Apeldoorn, The Netherlands. The building will consist out of 40 apartments, 8 apartments and a shared living room per level.
There will be at least two simulations to determine the available safe time in both escape routes as fire compartments. The first simulation will be an evacuation concept (concept according o he building code). The second simulation will be a stay-in-place concept. In the simulations he boundary conditions will be assumed word case, so that a sensitivity analysis is not necessary.

2 Theoretical background

2.1 Dutch National building code

Fire safety in the Dutch national building code has two gaols: to prevent casualties (injured and dead) and to prevent the spread of fire to neighbouring plots. Saving the building and preventing damage to the environment, monuments, public facilities or social interests are no goals of the Dutch national building code.

The Dutch national building code knows 4 general assumptions for fire safety on which the prescriptive regulations are based:

- Within 15 minutes after the ignition of the fire, the fire has been discovered and the fire brigade and the by fire threatened persons need to be informed;
- Within 15 minutes after the discovery of the fire the by fire threatened persons need to be evacuated with assistance from the fire brigade;
- The fire brigade arrives on location and is operational within 15 minutes after the fire is discovered;
- The fire brigade needs to have control over the fire within 60 minutes after the fire ignition. Which means that the spread of fire is prevented. Within the same time the last not self-reliant people have been evacuated by the fire brigade.

The national building code has rules and regulations in case of a fire that are based on redundancy. A building user must always have two ways for evacuating a building. In case of a fire one of the evacuation routes can be blocked by fire or smoke, in which case the building user can evacuate by using the second route.

2.1.1 Performance based approach

The national building code is based on prescriptive regulations and is not performance based. In a performance based approach project specific boundary conditions would be taken into account. A building code with prescriptive regulations uses a standard fire curve, while for a performance based approach natural fire characteristics, building characteristics and building users are taken into account. For a stay-in-place concept, a performance based approach should be used because a stay-in-place concept is not supported by the national building code

2.1.1.1 Natural fire characteristics

Natural fires depends on fuel characteristics and building characteristics, this means that natural fires are project-specific. Because natural fires depends on fuel characteristics and building characteristics, natural fires have different thermal loads than standard fires. The thermal load and the response of building elements, heat detectors, sprinkler heads and many more installations can be calculated when a natural fire is used.

The smoke generated by a natural fire changes the optical density in a room. The visibility of the building occupants is decreased due to the optical density of smoke.

When a natural fire concept is used the influence of active fire and smoke control systems can be taken into account. This can result in a decrease in thermal load and an increase of the available evacuation time.

A fire with natural fire conditions has three phases; a growing phase, a full development phase and a decay phase. During these phases combustion under natural fire conditions is usually incomplete, the effective contribution of the fire load to the energy release during a fire is smaller than the derated fire load. Under natural fire conditions the combustion is incomplete, not all materials are able to combust and from the materials that are combustible a part has incomplete combustion and generates smoke. This smoke is not purely CO_2, but also consist out of other particles such as carbon (C), carbon monoxide (CO) and water-vapour (H_2O) (Hurley, 2016).

A natural fire causes a thermal load on building occupants and elements by convention and radiation and causes an optical load on building occupants because of the optical density in the gas mass.

2.1.1.2 Building characteristics

Buildings can have multiple characteristics, there are building types, building functions and building constructions. Each of these characteristics can be categorised and multiple building characteristics can be linked with each other.

Building types

The national building code states five building type:

- New constructions,
- Existing constructions,
- Completely renovation,
- Partially renovated,
- Temporary constructions

Building functions

The national building code describes 12 building functions. This research focusses on 2 of those building functions: residential functions and healthcare functions.

Besides these two functions, a stay in place concept can be applied for gathering functions, detention function and accommodational functions. These functions are not included in this research.

Building constructions

The building constructions can be divided into external and internal separations constructions. These separations constructions can have different characteristics, such as thermal heavy constructions and thermal light constructions, constructions can be insulated and constructions can have different levels of air tightness.

Thermal heavy and thermal light constructions are characteristics of the internal and external separation constructions. Windows, doors and panels can be placed in the thermal heavy or thermal light constructions and are part of the internal and external separation constructions.

Thermal heavy constructions react different to a fire than thermal light constructions. The materials and the characteristics of the windows, doors and panels in the separation constructions influence the development of a fire. Thermal light separation constructions cannot buffer the energy released by a fire. This results in a steady state heat flux by conduction. Thermal heavy separation constructions can buffer the energy released by a fire. The heat flux through a thermal heavy construction is different in each material layer.

The characteristic thermal light or thermal heavy is determined by the thermal penetration depth. The thermal mass of a separation construction determines the amount of energy that is buffered in the material layer. Thermal mass is only relevant in thermal heavy material layers.

Building installations for fire safety

In order to alarm building occupants about a fire, smoke detectors are placed in the apartment for residential buildings. Stand alone optical smoke detection in residential functions is mandatory by the national building code. However most fire safety installations are not mandatory, except for buildings exceeding 70 meters in height. Smoke detection in escape routes and active fire control systems like sprinklers, active smoke control systems, overpressure systems or smoke outlet systems, can be activated by thermal or optical detection and may need to be applied in a stay-in-place concept.

2.1.1.3 Building users

Building users can have a big impact on the way a building is used. The behaviour of building users can impact the use of a building but also on the evacuation of a building. In case of fire a building user might choose the remain in the burning building or the escape the burning building. And even the escape route that the building users choose to take depends on the behaviour of the building user. Building users can already react different on the know concept as prescribed in the building code: escape in case of a fire. The stay-in-place concept is not a generally known concept for fire safety engineering and is not prescribed in the national building code. Because the stay-in-place concept is a relatively new concept, building users need to be taught how to use this concept in case of a fire.

Building users can be categorised into three categories:

- Self-reliant people
- Less self-reliant people
- Not self-reliant people

People that a categorised as self-reliant according to the regulations may not be self-reliant in case of fire. Elderly people who still live in their homes are qualified as self-reliant, however some of the elderly people buy/use customized care in order to live. These people can live on their own with a bit of help but in case of fire they are not self-reliant. According to the national building code a building needs to be evacuated within 6/15/20 minutes, however elderly people might not be fast enough to evacuate the building in time. For people that are qualified as self-reliant, who are not self-reliant in case of fire, for less self-reliant people and or not-self-reliant people, there should be another concept for fire safety than the one that we are familiar with.

2.2 Risk subsystems

The national building code has two main public objectives: personal safety (of building occupants and aid workers such as fire fighters) and protection of neighbouring plots and adjacent buildings (Geconsolideerde Staatsbladversie 20-01-2022, 2022). In order to achieve the two main public objectives there are five risk subsystems or sub objectives, related to the building code:

- The environment: neighbouring plots
- The building: load bearing structure
- The building compartments: the spread of fire and smoke
- The escape routes: building users
- The attack routes: aid workers such as fire fighters

When one of these risk subsystems cannot be guaranteed on itself, the other subsystems can be improved in order to meet the standards and to comply with the regulations.

In fire safety engineering the main objective is to evacuate the building occupants safely in acceptable conditions inside the building. In sustainable buildings that need to be fire resilient, safety of other risk subsystems, such as the reliability in case of fire of building structures and fire resistant separation constructions, is important too. A fire resilient building is possible with a high reliability. A stay-in-place concept for building occupants might be a safer option in a fire resilient building.

2.3 Assessment criteria for personal safety

Personal safety can be assessed by different criteria. According to the SFPE Handbook of Fire Protection Engineering there are Carbon monoxide concentrations, Hydrogen cyanide concentrations, Carbon dioxide concentrations, oxygen concentrations, indirect radiant heat flux to subject, air temperature, smoke optical density (and particulate concentration), irritant acid gas concentrations and concentrations of organic irritant species (Hurley, 2016). The toxicity of smoke becomes insignificant when the visibility in a compartment is more than 5 meter (Nieman Raadgevende Ingenieurs B.V., 2018). In order for residents to stay-in-place during a fire in an adjacent compartment, the temperature cannot exceed 70°C.

3 Case description

For the simulations a reference building is used which is a new construction. The design of the building will be a new 5 story apartment building. The building will be built in Apeldoorn, The Netherlands. The building will consist out of 40 apartments, 8 apartments and a shared living room per level.

3.1 Building characteristics

Building and apartments
The case study is a new 5 story apartment building with 40 apartments in total. Each floor will have 8 apartments, a shared living room and a small office. Each apartment will be its own fire compartment. The apartment has a combined living room and kitchen, a bedroom, a bathroom, an entrance hall, a storage room and a small utilities room. The total surface area of the apartment is 64 m^2. Each apartment has a balcony attached to the living room. Two vertical shafts connect the apartments with the apartments above. The shafts will have a 60 minutes fire separation. The technical drawings of the building are shown in attachment 1.

Fire compartments
Each apartment is a separate fire compartment. The walls between apartments will be 60 minutes fire resistant and the walls between the apartments and the hallway will also be 60 minutes fire resistant. This will be above the minimum according to the national building code. For a stay-in-place concept it might be necessary to create more reliable separation constructions.

Materials
For the CFAST calculation materials of the separation constructions need to be specified. There is a difference between the walls and the floor and ceiling. Table 3-1 specifies the materials used in the CFAST model.

Table 3-1. Materials used in the CFAST model.

Partition	Material	Thermal conductivity [W/m*K]	Thickness [mm]	Density [kg/m^3]	Specific heat [J/kg*K]	Emissivity [-]
Wall 1	Concrete	1.75	150	2200	1.0	0.94
Wall 2	Plasterboard	0.16	13	790	0.9	0.9
Floor	Concrete	1.75	150	2200	1.0	0.94
Ceiling	Concrete	1.75	150	2200	1.0	0.94

Airtightness
Airtightness is the volume flow through a separation construction of a building, measured at a pressure difference of 10 Pa. the airtightness is calculated with the following formula:

$$Q_{v;10} = C * \Delta P^n \qquad (1)$$

Where:

- $Q_{v;10}$ is the volumetric leakage airflow rate at 10 Pa expressed in m^3/h
- C is the air leakage coefficient expressed in $m^3/h*Pa^{-n}$
- ΔP is the pressure difference across the building expressed in Pa
- n is the airflow exponent ($0.5 \leq n \leq 1.0$)[1]

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[1] The airflow exponent n is 0,5 for large openings and 1.0 for perfect laminar flows. The airflow exponent is between 0.7 and 0.8 for flows in buildings, in CFAST the airflow exponent needs to be filled in as 0.5.

The NEN 2687 knows two levels of airtightness, the third level of airtightness is based on the passive house principle. The levels of airtightness are shown in Table 3-2. Level of airtightness according to NEN 2687.Table 3-2.

Table 3-2. Level of airtightness according to NEN 2687.

Class	Qualification	$Q_{v;10}$ (dm^3/s*m^2)
1	Basic	<1.0
2	Good	0.4 – 0.6
3	Excellent	< 0.15

The minimum airtightness of a building according to the national building code is a Qv;10 of 0.2 m^3/s (200 dm^3/s) ('Bouwbesluit 2012 online', 2012). This is a Qv;10 of 3.6 dm^3/s*m^2 for an apartment of 56 m^2. Comparing it to the classification of a energy efficient building which has a Qv;10 of 0.4-0.6 dm^3/s*m^2, the requirements of the National Building Code are not high. For this simulations the airtightness of the building will differ for each scenario. The basic Qv;10 will be 0.45 dm^3/s*m^2 for the external separation construction and 1.35 dm^3/s*m^2 for the internal separation construction. The Qv;10 value corresponds with the national building code and is used for BENG. Based on this value there will also be scenarios with a Qv;10 value 3 times better for the internal separation, 3 times better for the external separation and 9 times better for the internal separation construction. This is based on measurements taken by Nieman which resulted in an internal airtightness which is approximately 3 times worse than the external airtightness (Nieman Raadgevende Ingenieurs B.V., 2019). The Qv;10 value used in this project are shown in Table 3-3.

Table 3-3. Airtightness of the building.

	Qualification	$Q_{v;10}$ (dm^3/s*m^2)
1	Basic	1.35
2	Good	0.45
3	Excellent	0.15

In order to calculate the equivalent surface area the following formula has been used:

$$A_{netto} = \frac{C}{8,33} \cdot (\Delta P)^{(n-0.5)} \qquad (2)$$

Where:

- A is the equivalent surface area expressed in dm^2
- C is the air leakage coefficient expressed in m^3/h*Pa^{-n}
- P is the pressure expressed in Pa
- n is the flow exponent

When using formula 2 for the equivalent surface area for air leakages, the equivalent surface area depends of the pressure difference between indoor and outdoor. The equivalent surface area is calculated for a reference pressure difference of 10 Pa. This means that for pressure differences <10 Pa the equivalent surface area is overestimated and for pressure difference >10 Pa the equivalent surface area is underestimated. This is the result of a flow exponent of n>0.5

The equivalent surface area is defined for each air leakage path. Table 3-4 shows the equivalent surface area for scenario 1.

Table 3-4. Example of the equivalent surface area for scenario 1.

Separation construction	Qv;10 [dm³/s]	Qv;10 [dm³/s*m²]	$A_{equivalent}$ [dm²]	$A_{equivalent}$ [m²]	Height [m]	Vent width [m]
Façade	28,125	0.45	1.07	0.0107	2.85	0.0037
Floor	21,094	1.35	0.80	0.0080	2.85	0.0028
Ceiling	21,094	1.35	0.80	0.0080	2.85	0.0028
Door in separation construction		-	0.21	0.0021	2.85	0.0007
construction corridor		1.35	2.99	0.0299	2.85	0.0105
leakage area shaft				0.0060	0.06	0.1000
Separation construction corridor	84,375	1.35	3.20	0.0260	2.85	0.0091
Separation construction 1	21,094	1.35	0.80	0.0080	2.85	0.0028
Separation construction 2	21,094	1.35	0.80	0.0080	2.85	0.0028

Vents

The equivalent surface area calculated based on the assumptions made for the airtightness need to be included in the model. The equivalent surface area is included in the model by creating small openings in the compartment. These small openings or small vents need to be applied over the entire height of the compartment. By applying the vents over the entire height, the fire behaviour is affected as little as possible. The vent measurements used in the simulation are shown in a table for each scenario. Doors and windows will be opened and closed in the simulations, see Table 3-5.

Table 3-5. specifics of the doors and windows.

Opening	From compartment	Towards compartment	Width [m]	Height [m]	Opening [s]	Closing [s]	Percentage of opening [%]
Door	Compartment 3	Compartment 30	1.26	2.4	60	90	100
Window (small)	Compartment 3	Outside	0.94	1.74	0	300*	10
Window (large)	Compartment 3	Outside	3.35	2.54	0	300*	0

*after 300 s the windows in the façade will be completely open because of flash over.

The mechanical ventilation has been neglected for the simulations of this project based on a worst case approach. The capacity of an individual mechanical ventilation system has a small influence on the fire scenario, smoke production and the smoke spread. The only effect it can have is positive due to the fact that it extracts smoke from the fire compartment.

3.2 Fire characteristics

Fire object

A natural fire is used in the simulations. The molecular formula of the combustion materials is $C_4H_6O_3$. The heat release rate of the fire is shown in Figure 3-1. The growth rate of the fire is 300 seconds according to NEN-EN 1991-1-2 Eurocode 1: Belastingen bij brand. Because of modern furnishing the growth rate for the simulations is 150 seconds in stead of 300 s (according to Eurocode 1), until the maximum object size is reached. Then the RHR remains constant.

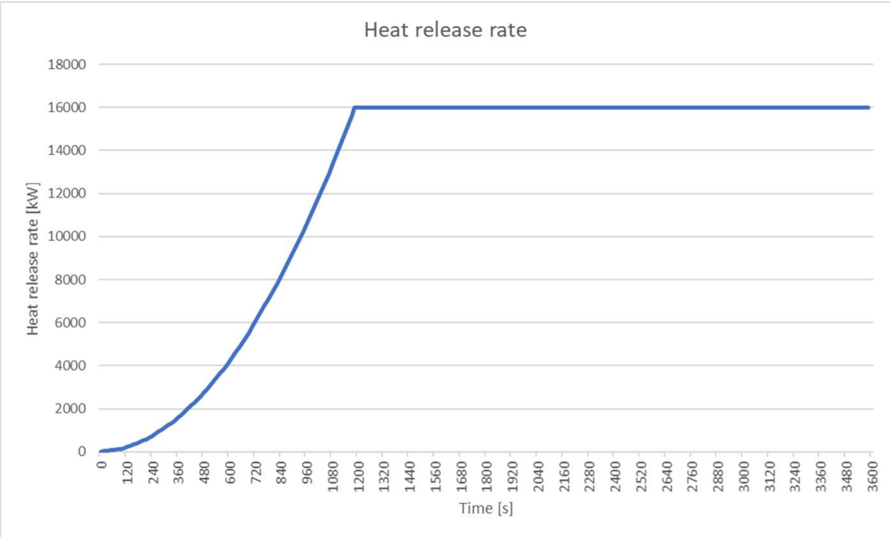

Figure 3-1. Heat release rate (HRR) of $C_4H_6O_3$.

The fire characteristics used in the simulations are:

- Time constant = 150 s (fast development)
- HRHPUA = 250 kW/m^2
- Max fire area = 64 m^2
- Lower oxygen level (LOL) = 0.1 (10%) (McGrattan et al., 2016)
- Heat of combustion = 17,500 kJ/kg
- Soot yield = 0.0264
- CO yield = 0.0104

The soot yield and the CO yield are applicable of fuel controlled fires, when there is enough oxygen in the room. The yields will increase when the fire is a ventilation controlled fire, as shown in Figure 3-2 (Quintiere, 2017). In which an equivalence ratio $\Phi < 1$ is a fuel controlled fire and an equivalence ratio $\Phi > 1$ is a ventilation controlled fire.

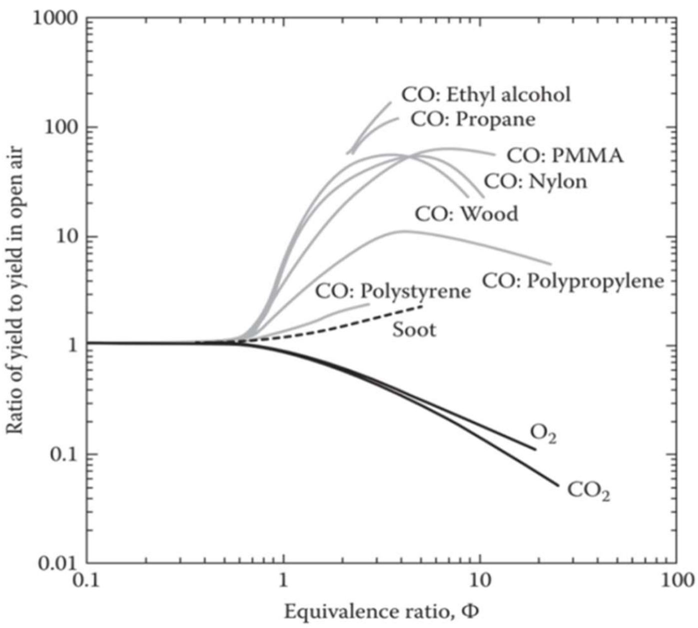

Figure 3-2. Ratio of yield to yield in open air.

4 Computational Approach

4.1 Software

The consolidated model of fire and smoke (CFAST) is used to simulate the impact of afire in an airtight multi-story multicompartment residential building. CFAST can calculate the time-evolving distribution of smoke, fire gases and temperature throughout multiple compartments if a building dure a fire by using a two-zone model (National Institute of Standards and Technology, 2019).

Out of CFAST, OZONE, CONTAM, BRISK and FDS, CFAST is the most appropriate program for a study towards the impact of mechanical ventilation on the pressure increase in a dwelling during a fire (Tenbült, 2017). Based on the research of Nick Tenbült and Marc Scholman (Scholman, 2020), CFAST is the most suitable program for modelling and simulating during this master project.

4.2 Model

It is difficult to determine the exact airtightness of a multi-story multi-compartment building that has not yet been build. In order to model the building assumptions have been made based on the regulations of the national building code for airtightness of the outer shell.

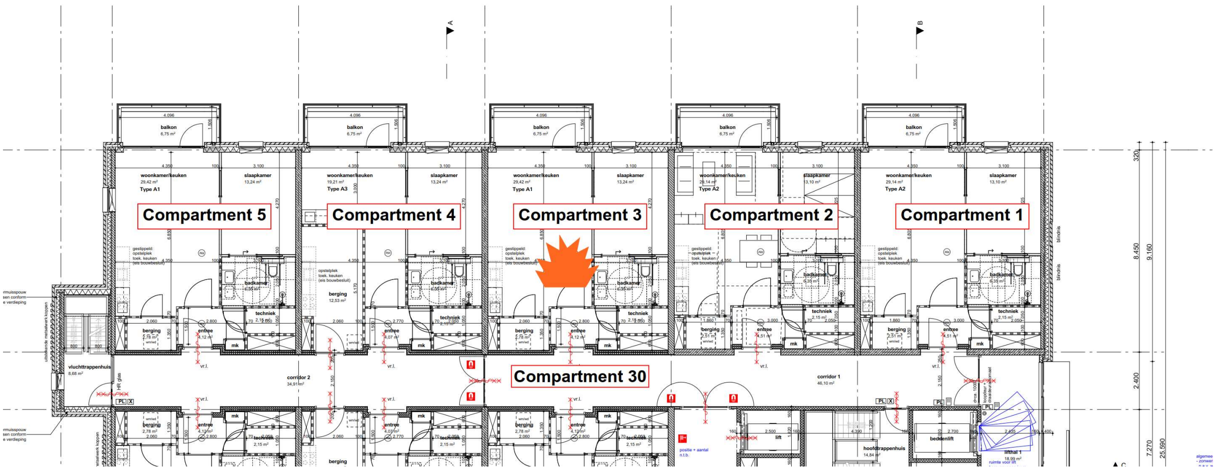

Figure 4-1. Model of building with the fire simulation.

4.3 Scenarios

There are four scenarios modelled and simulated for this project. All four scenarios will have the same natural fire conditions. The fire is modelled in the same compartment at the same spot for each of the simulations, as shown in Figure 4-1. The compartment is vertically connected with the compartments above via a shaft in which the mechanical ventilation ducts are situated. Via a door the compartment is connected to a hallway and on the right and left on the compartment are similar fire compartments. In Table 4-1 the conditions for the scenarios are shown.

The Qv.10 is used to calculate the equivalent surface area of openings in the façade. The Qv.10 is also used for the equivalent surface area of openings in the internal separation constructions. The calculations for the Qv.10 are shown in appendix 2.

Table 4-1. Qv.10 scenarios.

Scenario	External Qv10	Internal Qv10	Qualification
1	0.45	1.35	Good
2	0.45	0.45	Good
3	0.15	0.45	Excellent
4	0.15	0.15	Excellent

For this research a scenario is modelled and simulated in which in one of the fire compartments a fire is burning. The compartment is vertically connected to the compartments above via a shaft in which the mechanical ventilation ducts are situated.

4.4 Model modification

In order to simulate a fire in the building, the model of the apartments in the building has been changed. The shaft that connects the floors has been placed outside of the apartment into the hallway, the apartment is modelled as a rectangle, as shown in Figure 4-2. An overview of the air leakage paths are shown in Figure 4-3.

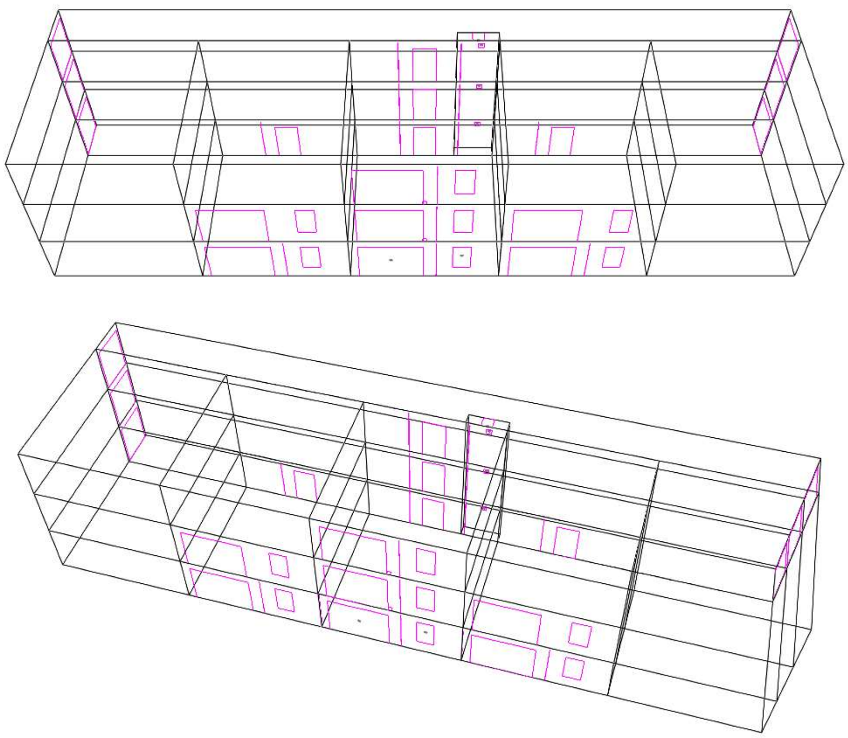

Figure 4-2. Model in CFAST.

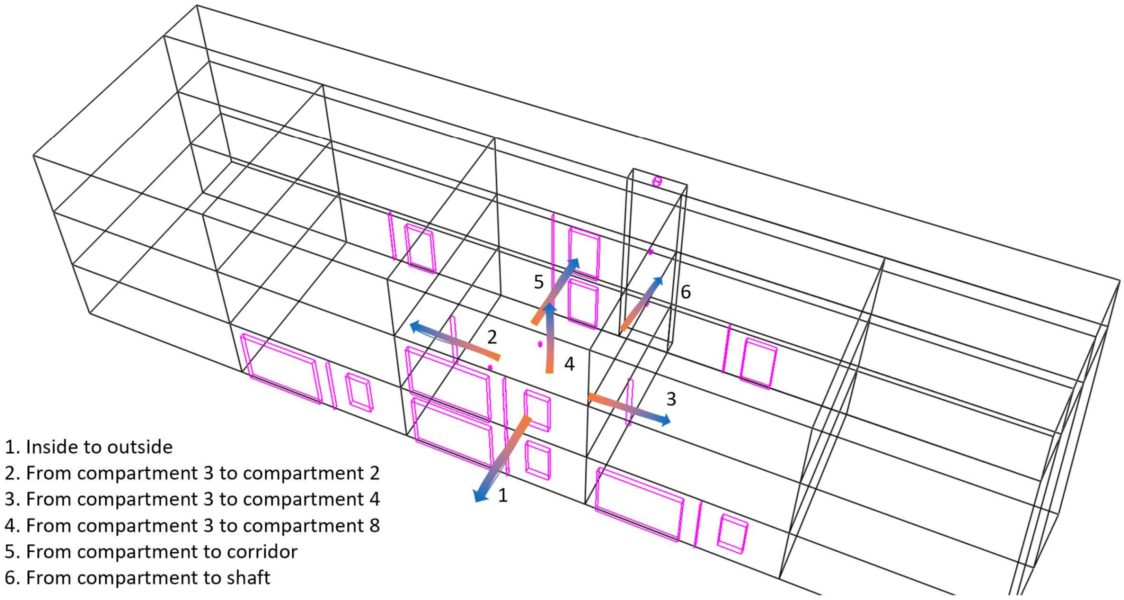

Figure 4-3. Air leakage paths through the building.

The positions of the compartments is shown in Figure 4-4 and Table 4-2.

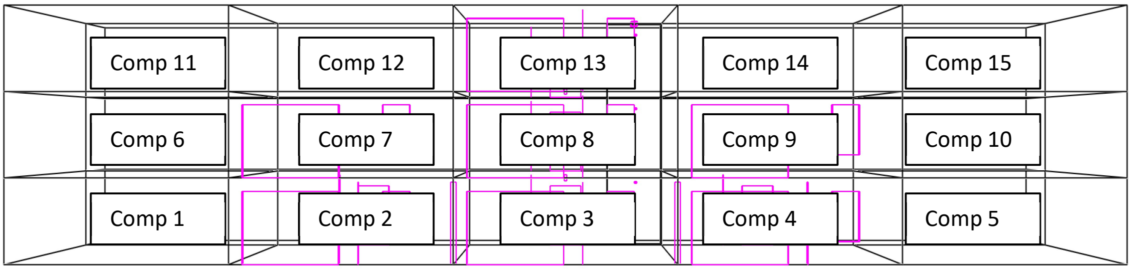

Figure 4-4. Overview of the compartments.

Table 4-2. Position of the compartments.

Compartment	**Position of the compartment**
Compartment 2	Adjacent compartment left
Compartment 3	Fire compartment
Compartment 4	Adjacent compartment right
Compartment 8	Adjacent compartment above
Compartment 13	Adjacent compartments two above
Compartment 30	Adjacent corridor

5 Results

5.1 Assessment stay-in-place concept

The stay-in-place concept is an application for fire-safety in the national building code, however a stay-in-place concept can be used in buildings. The national building code prescribes building users to evacuate the building is case of a fire or an emergency through escape routes. When personal safety can not be guaranteed via the escape routes, an equivalent fire safety concept van be used. The stay-in-place concept has been applied to buildings in this way. In order to prove the equivalence of the stay-in-place concept, fire safety engineering calculations and models need to be show to the local authorities and the fire brigade.

5.2 Assessment airtightness

The airtightness will be assessed by comparing 4 scenarios. The results of scenario 1 are compared with the results of scenarios 2, 3 and 4. With the results of the simulations an assessment of the stay-in-place concept can be made based on the difference in airtightness between the scenarios. Two assessments can be made:

- What happens when the internal airtightness improve?
- What happens when the internal and external airtightness improve?

The comparison is based on the assessment criteria: optical density and the temperature in the 2 adjacent compartments, the compartment above and the corridor.

Scenario 1
For the baseline model of the case study – scenario 1 –, the CFAST input data is included in attachment 3. Figure 5-1 and Figure 5-3 graphically summarizes the simulation results in the compartment (comp 3), the 2 adjacent compartments (comp 2 & 4), the compartment above (comp 8) and the corridor (comp 30). The optical density conditions are used as a limit as described in section 2.3.

The limit for the optical density is exceeded in both adjacent compartments, the compartment above and in the corridor. The optical density in the adjacent compartments has a small peak in which the limit of 5 meters is exceeded after 90 seconds. After 150 seconds the optical density drops below the limit in these compartments. After 195 seconds the limit is exceeded again in the adjacent compartments and drops below the limit again after 435 seconds. The optical density in the compartment above exceed the limit of 5 meters after 90 seconds and the optical density in the adjacent corridor exceed the limit of 5 meters after 90 seconds. The optical density in the compartment above drops below the limit after 540 seconds.

The drop in optical density after 150 and the peak after 195 seconds are a result of the pressure difference at those times. After 135 seconds the pressure in the fire compartment drops from 336 Pa to -0.1 Pa and increases after 180 seconds from 20 Pa to 2,240 Pa. Due to the opening of the compartment door, fresh air is added to the fire, which increases the heat release rate of the fire again.

The temperature limit of 70°C is only exceeded in the corridor. The temperature in the adjacent compartments and in the compartment above stays below 35°C.

Table 5-1. Assumptions of boundary conditions for the vents of scenario 1.

Separation construction	Qv;10 [dm³/s]	Qv;10 [dm³/s*m²]	$A_{equivalent}$ [dm²]	$A_{equivalent}$ [m²]	Height [m]	Vent width [m]
Façade	28,125	0.45	1.07	0.0107	2.85	0.0037
Floor	21,094	1.35	0.80	0.0080	2.85	0.0028
Ceiling	21,094	1.35	0.80	0.0080	2.85	0.0028
Door in separation construction		-	0.21	0.0021	2.85	0.0007
construction corridor		1.35	2.99	0.0299	2.85	0.0105
leakage area shaft				0.0060	0.06	0.1000
Separation construction corridor	84,375	1.35	3.20	0.0260	2.85	0.0091
Separation construction 1	21,094	1.35	0.80	0.0080	2.85	0.0028
Separation construction 2	21,094	1.35	0.80	0.0080	2.85	0.0028

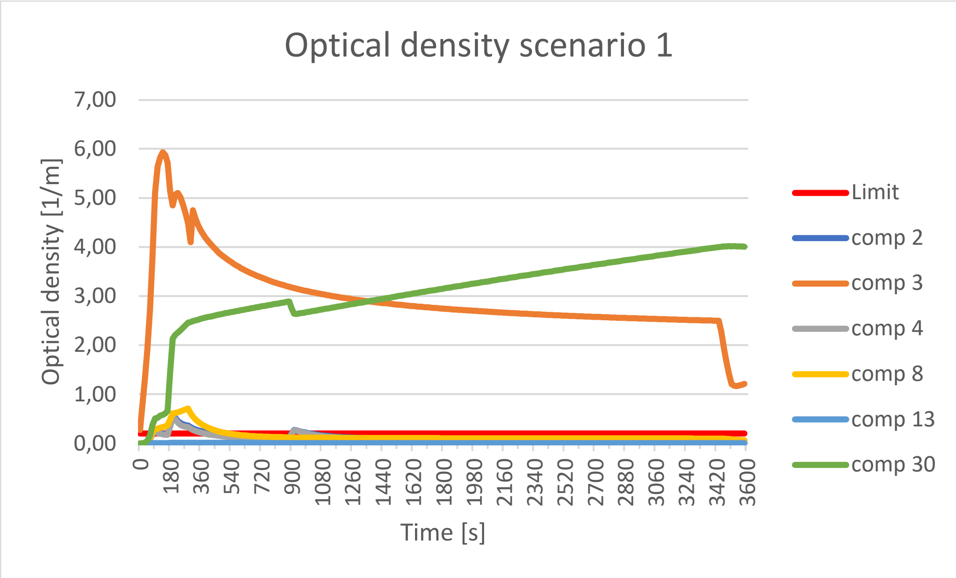

Figure 5-1. Optical density in different compartments during the simulation of scenario 1.

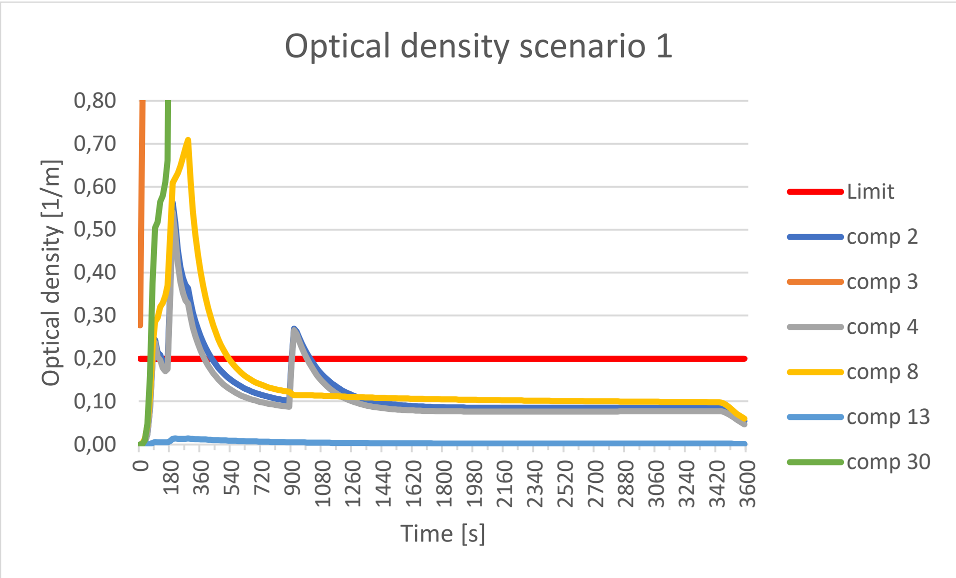

Figure 5-2. Close-up of the optical density in different compartment during the simulation of scenario 1.

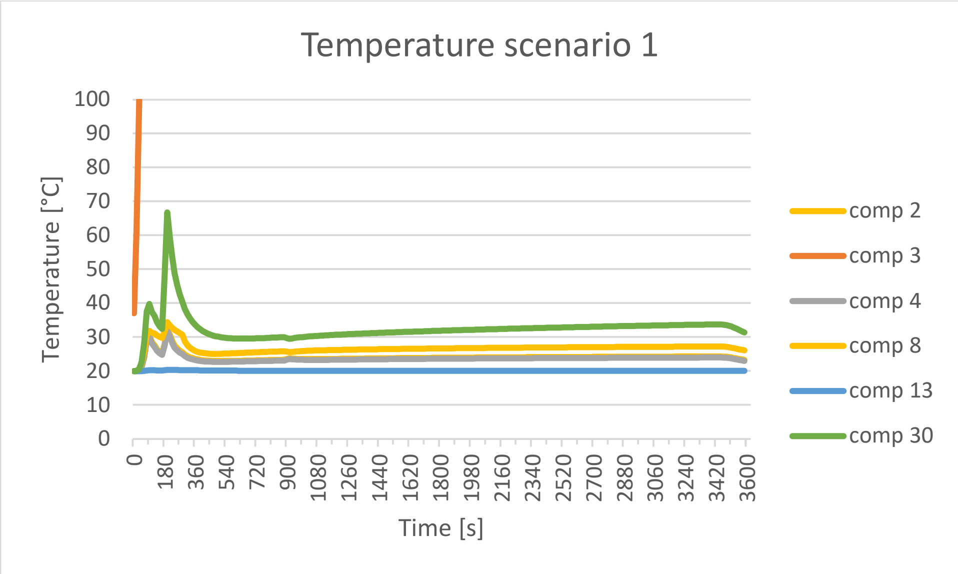

Figure 5-3. Temperatures in different compartments during the simulation of scenario 1.

Scenario 2
The limit for the optical density is exceeded in both adjacent compartments, the compartment above and in the corridor. The optical density in the adjacent compartments has a small peak in which the limit of 5 meters is exceeded after 105 seconds. After 120 seconds the optical density drops below the limit in these compartments. After 195 seconds the limit is exceeded again in the adjacent compartments and drops below the limit again after 390 seconds. The optical density in the compartment above exceed the limit of 5 meters after 105 seconds and the optical density in the adjacent corridor exceed the limit of 5 meters after 105 seconds. The optical density in the compartment above drops below the limit after 495 seconds.

The drop in optical density after 120 and the peak after 195 seconds are a result of the pressure difference at those times. After 105 seconds the pressure in the fire compartment drops from 16,058 Pa to -680 Pa and increases after 180 seconds from 180 Pa to 10,705 Pa. Due to the opening of the compartment door, fresh air is added to the fire, which increases the heat release rate of the fire again.

The temperature limit of 70°C is only exceeded in the corridor. The temperature in the adjacent compartments and in the compartment above stays below 35°C.

Table 5-2.Assumptions of boundary conditions for the vents of scenario 2.

Separation construction	Qv;10 [dm³/s]	Qv;10 [dm³/s*m²]	$A_{equivalent}$ [dm²]	$A_{equivalent}$ [m²]	Height [m]	Vent width [m]
Façade	28.125	0.45	1.07	0.0107	2.85	0.00375
Floor	7.031	0.45	0.27	0.0027	2.85	0.00094
Ceiling	7.031	0.45	0.27	0.0027	2.85	0.00094
Door in separation construction		-	0.21	0.0021	2.85	0.00074
construction corridor		0.45	0.86	0.0086	2.85	0.0030
leakage area shaft				0.0060	0.06	0.1000
Separation construction corridor	28.125	0.45	0.86	0.0047	2.85	0.00164
Separation construction 1	7.031	0.45	0.27	0.0027	2.85	0.00094
Separation construction 2	7.031	0.45	0.27	0.0027	2.85	0.00094

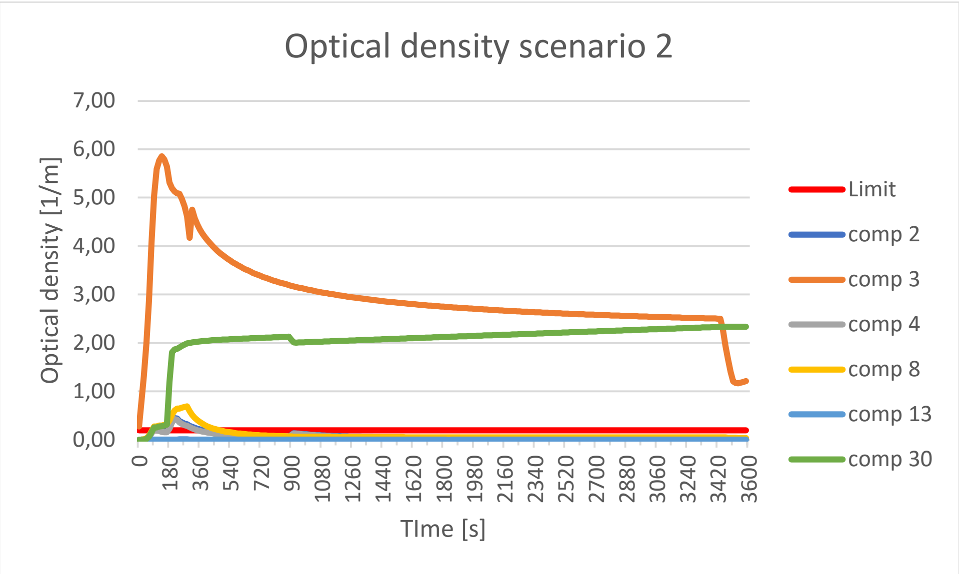

Figure 5-4. Optical density in different compartments during the simulation of scenario 2.

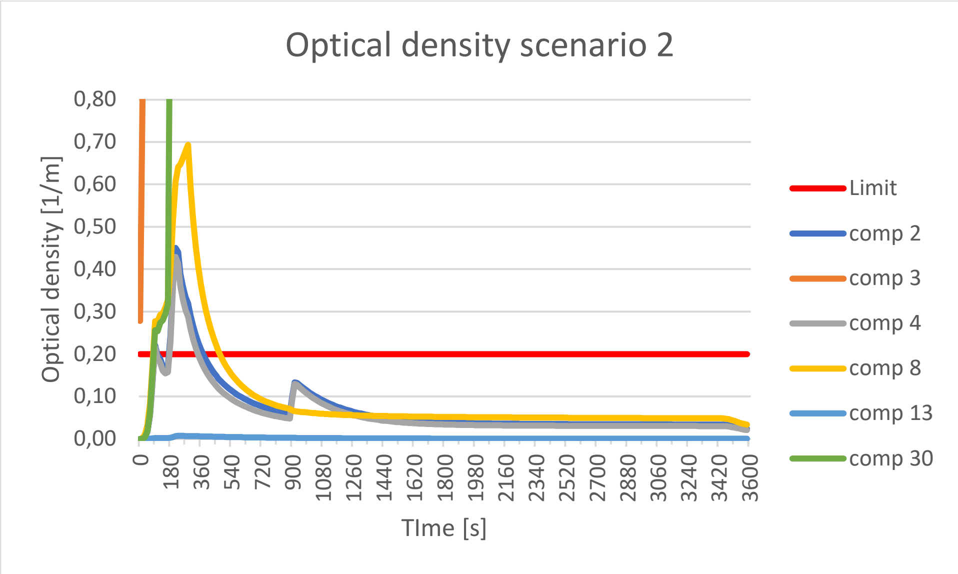

Figure 5-5. Close-up of the optical density in different compartment during the simulation of scenario 2.

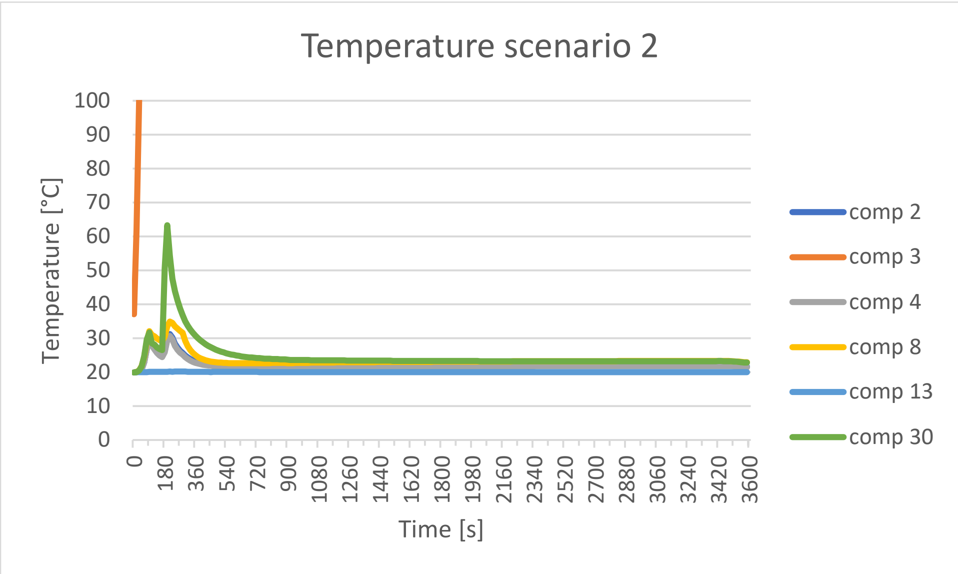

Figure 5-6. Temperatures in different compartments during the simulation of scenario 2.

Scenario 3

The limit for the optical density is exceeded in both adjacent compartments, the compartment above and in the corridor. The optical density in the adjacent compartments exceed the limit of 5 meters after 90 seconds, the optical density in the compartment above exceed the limit of 5 meters after 75 seconds and the optical density in the adjacent corridor exceed the limit of 5 meters after 90 seconds. The optical density in the adjacent compartments drops below the limit of 5 meters after 435 seconds. The optical density in the compartment above drops below the limit after 510 seconds.

The temperature limit of 70°C is only exceeded in the corridor. The temperature stays below 35°C in the adjacent compartments and below 40°C in the compartment above.

Table 5-3. Assumptions of boundary conditions for the vents of scenario 3.

Separation construction	**Qv;10 [dm³/s]**	**Qv;10 [dm³/s*m²]**	**$A_{equivalent}$ [dm²]**	**$A_{equivalent}$ [m²]**	**Height [m]**	**Vent width [m]**
Façade	9.375	0.05	0.36	0.0036	2.85	0.00125
Floor	7.031	0.15	0.27	0.0027	2.85	0.00094
Ceiling	7.031	0.15	0.27	0.0027	2.85	0.00094
Door in separation construction		-	0.21	0.0021	2.85	0.00074
construction corridor		0.15	0.86	0.0086	2.85	0.0030
leakage area shaft				0.0060	0.06	0.1000
Separation construction corridor	28.125	0.15	0.86	0.0047	2.85	0.00164
Separation construction 1	7.031	0.15	0.27	0.0027	2.85	0.00094
Separation construction 2	7.031	0.15	0.27	0.0027	2.85	0.00094

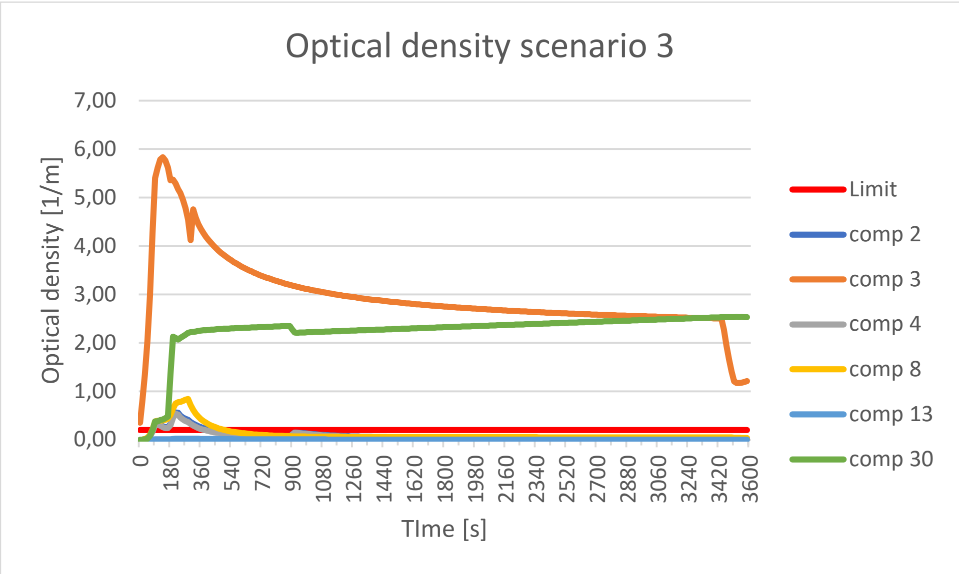

Figure 5-7. Optical density in different compartments during the simulation of scenario 3.

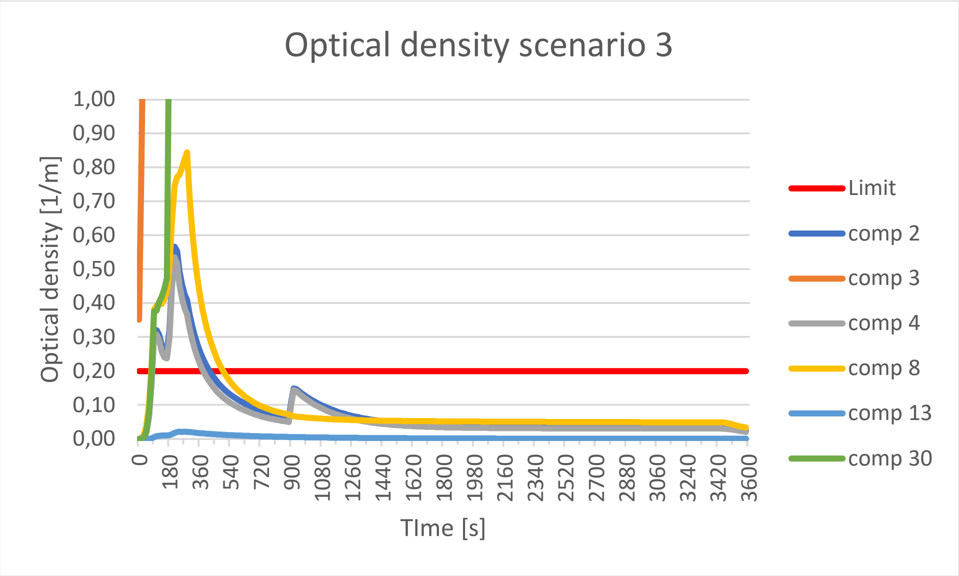

Figure 5-8. Close-up of the optical density in different compartment during the simulation of scenario 3.

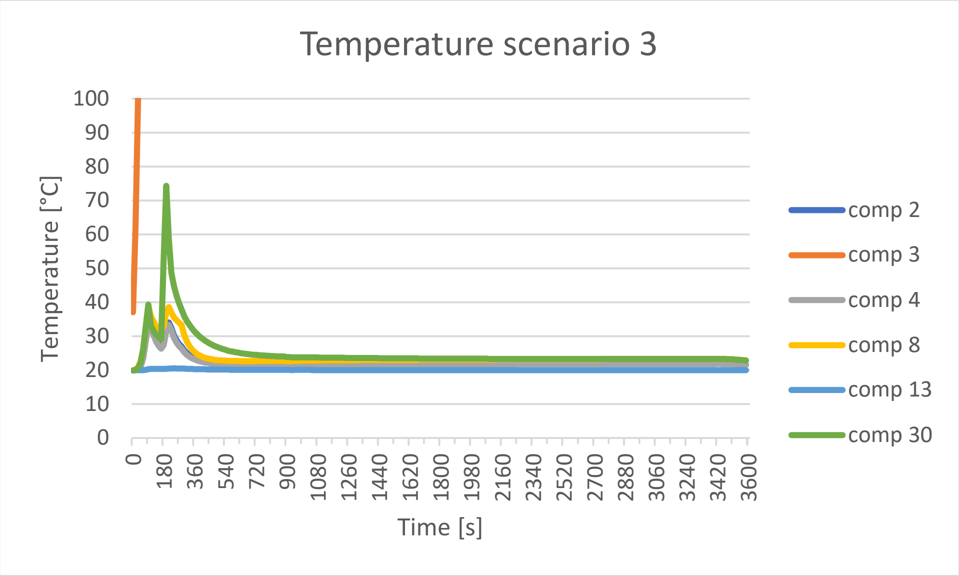

Figure 5-9. Temperatures in different compartments during the simulation of scenario 3.

Scenario 4

The limit for the optical density is exceeded in both adjacent compartments, the compartment above and in the corridor. The optical density in the adjacent compartments exceed the limit of 5 meters after 150 seconds, the optical density in the compartment above exceed the limit of 5 meters after 105 seconds and the optical density in the adjacent corridor exceed the limit of 5 meters after 75 seconds. The optical density in the adjacent compartments drops below the limit of 5 meters after 390 seconds. The optical density in the compartment above drops below the limit after 435 seconds.

The temperature limit of 70°C is only exceeded in the corridor. The temperature in the adjacent compartments and in the compartment above stays below 30°C.

Table 5-4. Assumptions of boundary conditions for the vents of scenario 4.

Separation construction	Qv;10 [dm³/s]	Qv;10 [dm³/s*m²]	$A_{equivalent}$ [dm²]	$A_{equivalent}$ [m²]	Height [m]	Vent width [m]
Façade	9.375	0.05	0.36	0.0036	2.85	0.00125
Floor	2.344	0.05	0.09	0.0009	2.85	0.00031
Ceiling	2.344	0.05	0.09	0.0009	2.85	0.00031
Door in separation construction		-	0.21	0.0021	2.85	0.00074
construction corridor		0.05	0.14	0.0014	2.85	0.0005
leakage area shaft				0.0060	0.06	0.1000
Separation construction corridor	9.375	0.05	0.14	-0.0024	2.85	-0.00086
Separation construction 1	2.344	0.05	0.09	0.0009	2.85	0.00031
Separation construction 2	2.344	0.05	0.09	0.0009	2.85	0.00031

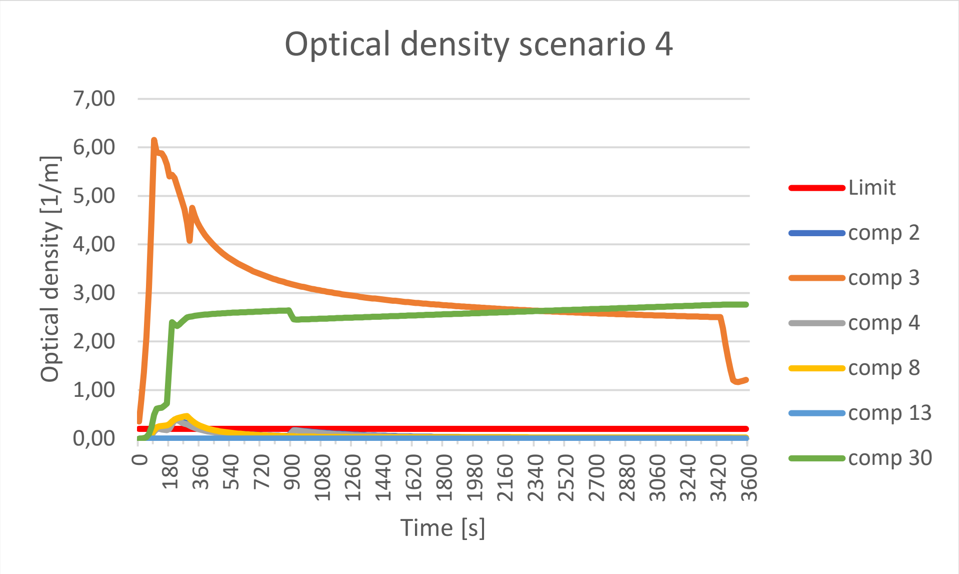

Figure 5-10. The optical density in different compartments during the simulation of scenario 4.

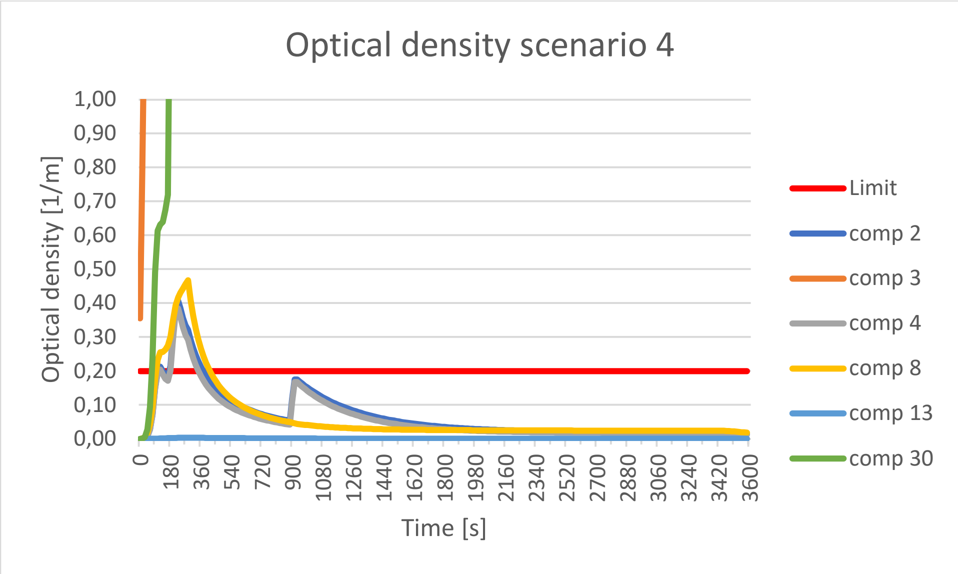

Figure 5-11. Close-up of the optical density in different compartment during the simulation of scenario 4.

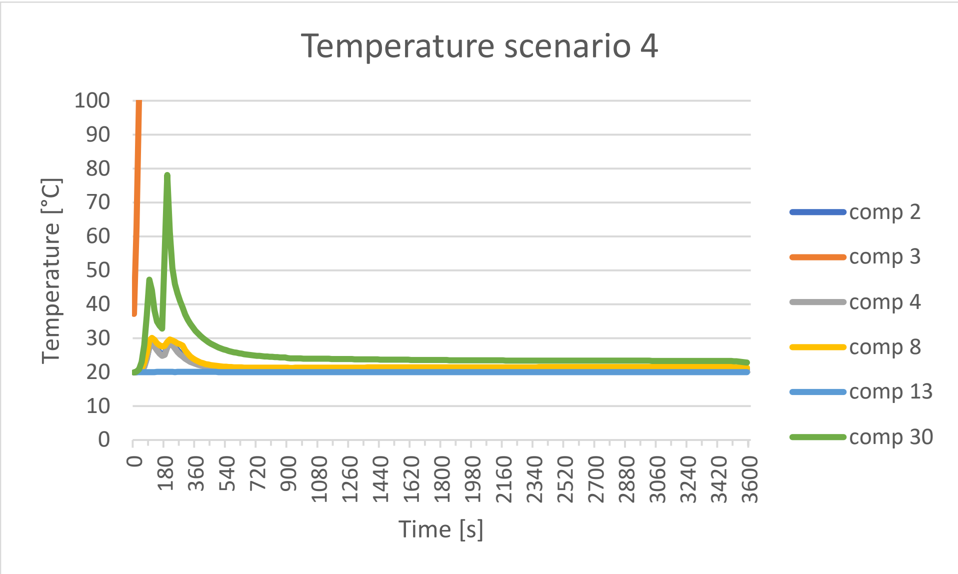

Figure 5-12. Temperatures in different compartments during the simulation of scenario 4.

5.3 Evaluation

5.3.1 Initial research

Adjacent compartments

The different scenarios show that the limit of the optical density is exceeded in all of the compartments, except for compartment 13, which is situated 2 compartments above the fire compartment. Despite the limit of the optical density is exceeded in every scenario, improving the airtightness does have a positive effect on the smoke spread. The optical density is increased which means that the safety level is increased. Table 5-5 shows that improving the airtightness does have an effect on the smoke propagation. The results show that improving the airtightness of the internal separation construction has a big effect on the smoke propagation. This is shown in the results of scenario 2 in comparison to scenario 1 and in the results of scenario 4 in comparison to scenario 3.

Table 5-5. Reducing smoke propagation by airtight separation constructions.

	Improvement			
	Compartment 2*	Compartment 4*	Compartment 8*	Compartment 30*
Scenario 1	baseline			
Scenario 2	29%	29%	45%	49%
Scenario 3	32%	32%	41%	50%
Scenario 4	67%	68%	70%	50%

*compartment 2 and 4: adjacent to the fire compartment on the same level; compartment 8: compartment above fire compartment; compartment 30: corridor adjacent to fire compartment.

The improvements as shown in Table 5-5 are visually shown in Figure 5-13, Figure 5-14, Figure 5-15, and Figure 5-16.

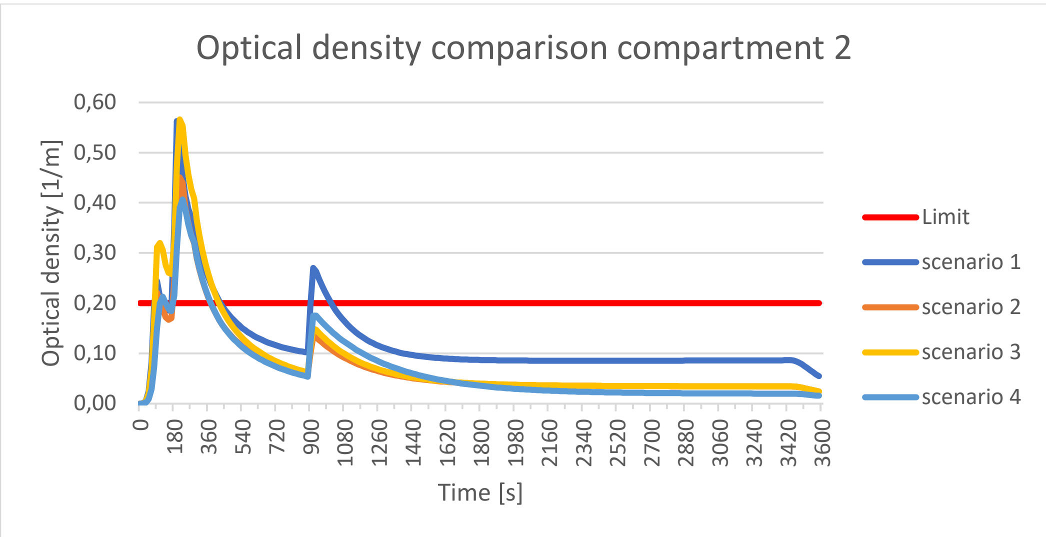

Figure 5-13. Comparison of the optical density for different scenarios in adjacent compartment 2.

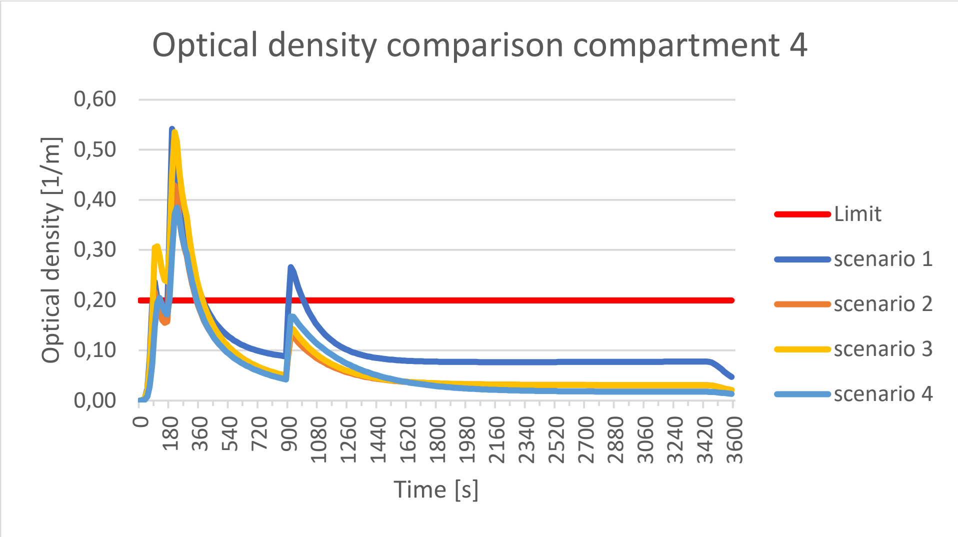

Figure 5-14. Comparison of the optical density for different scenarios in adjacent compartment 4.

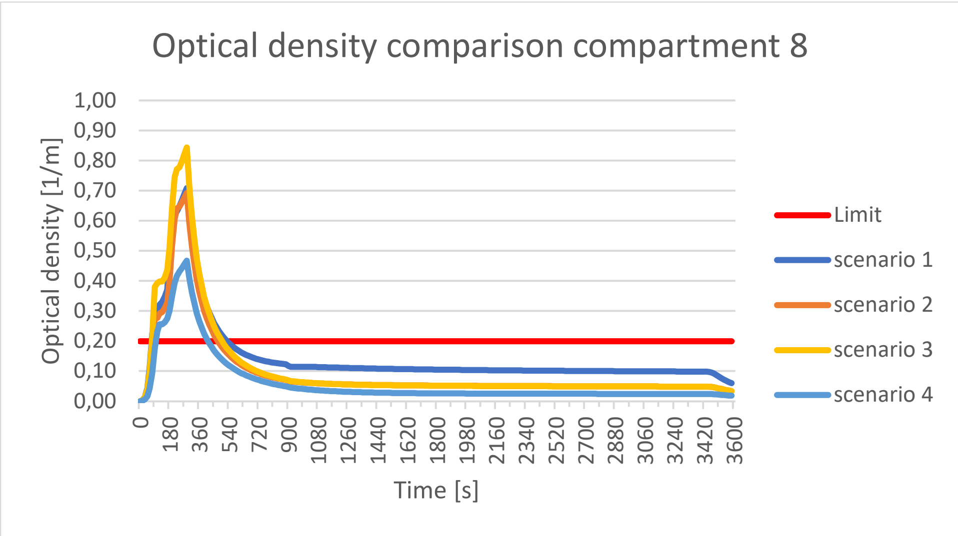

Figure 5-15. Comparison of the optical density for different scenarios in compartment 8 above the fire compartment.

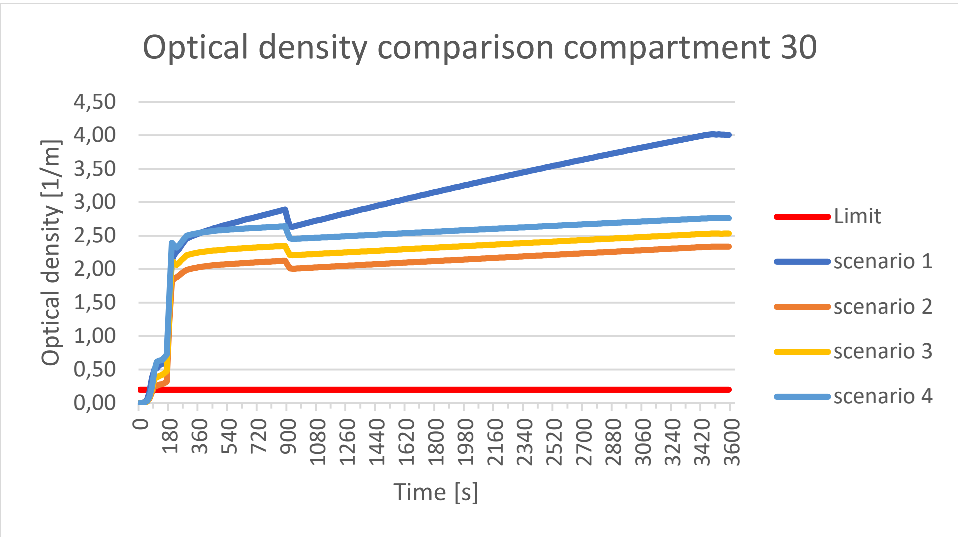

Figure 5-16. Comparison of the optical density for different scenarios in adjacent corridor, compartment 30.

Fire compartment
The temperature for the adjacent compartment is shown for each scenario, however the temperature in the fire compartment is not shown clearly in those figures. In Figure 5-17 the temperature in compartment 3 is shown for every scenario.

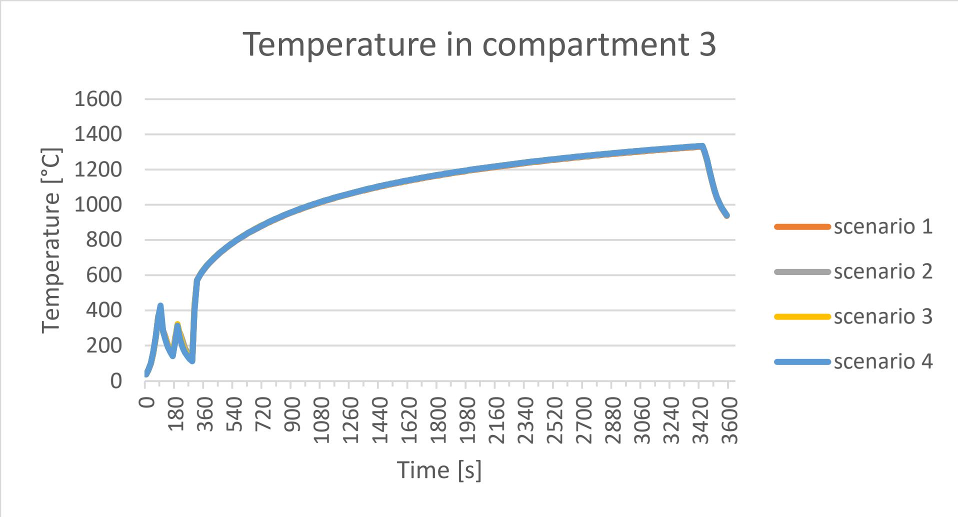

Figure 5-17. Temperature in compartment 3.

Figure 5-17 clearly shows two small peaks before the temperature rises. Those peaks are important for the results of the simulation. The first peak at 90 seconds shown that after 90 seconds the oxygen in the fire compartment is used by the fire. The second peak at 210 seconds happens due to the fact that the door in the fire compartment is opened 180 seconds after the start of the fire, and closed 30 seconds later at 210 seconds. At 300 seconds the temperature in the fire compartment is lowest during the simulation. The assumption was that the windows would break after 5 minutes (300 seconds) due to the temperature. Modern windows with insulated double glazing or triple glazing do not break at the temperatures shown in the first 300 seconds in Figure 5-17. However because the assumption was that the windows would break after 300 seconds the temperature increases rapidly. The same development can be seen in the heat release rate as shown in Figure 5-18.

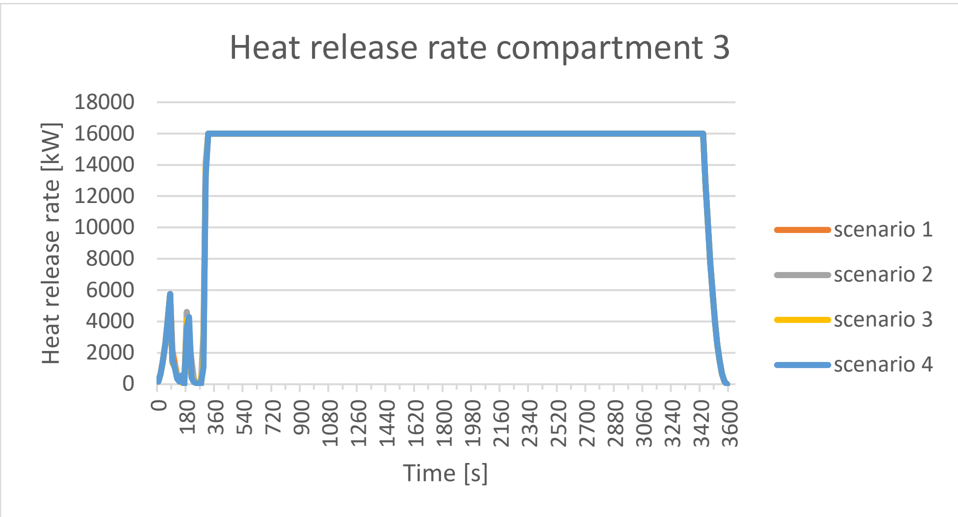

Figure 5-18. Heat release rate in compartment 3.

Because the assumption of the glass breaking was wrong, addition sublimations have been made, in which the glass does not break and will stay intact for 60 minutes during the simulation.

5.3.2 Additional simulations

Because the wrong assumption was made about the windows in the first four simulations, additional simulations have been made where the windows do not break during the simulation. This results in different developments of the heat release rate and temperature during the additional simulation, as shown in Figure 5-19 and Figure 5-20.

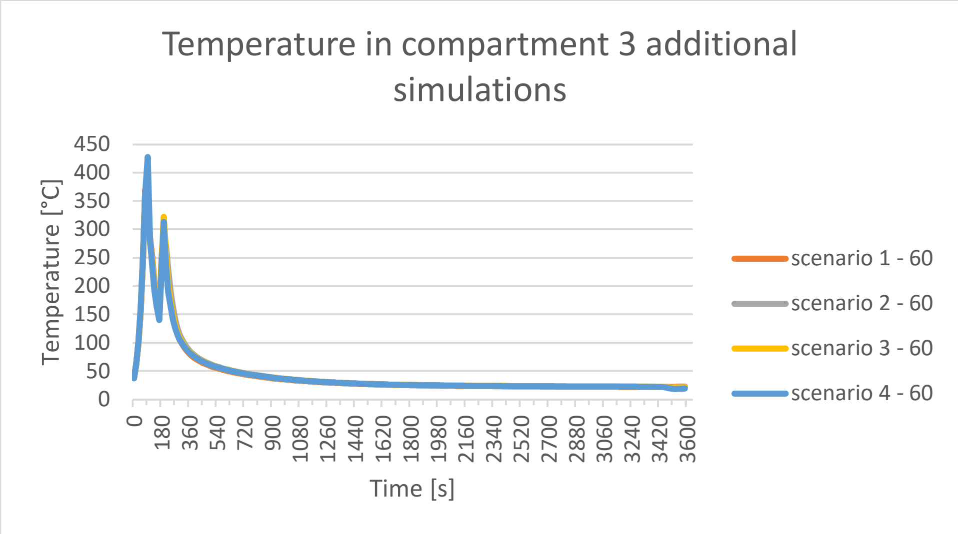

Figure 5-19. Temperature development in compartment 3 during additional simulations.

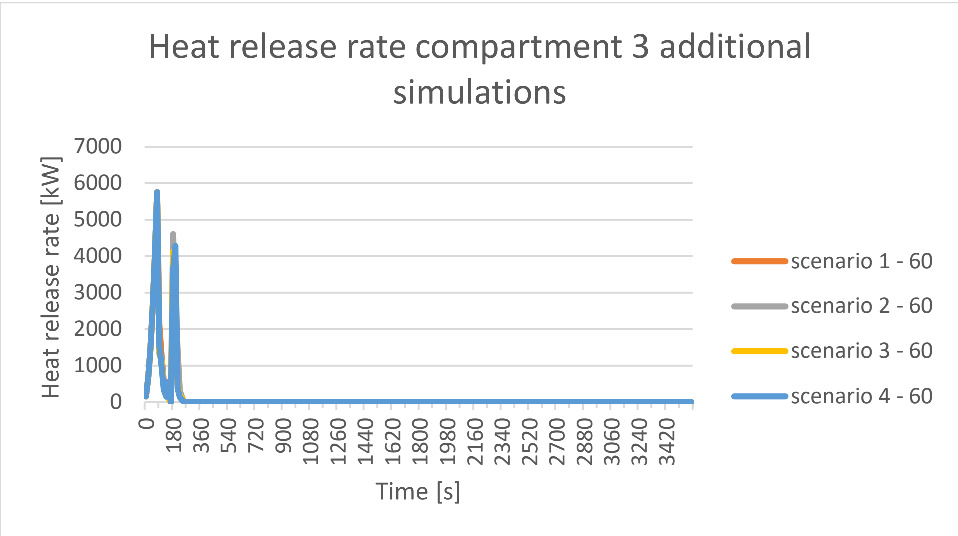

Figure 5-20. Heat release rate development in compartment 3 during additional simulations.

The peaks shown in Figure 5-19 and Figure 5-20 show the same start as in the first simulations. The fire develops till 90 seconds when the oxygen is depleted, after 180 seconds the door is opened and the fire develops again until 210 seconds when the door is closed again. Because the windows do not break in these simulations, the heat release rate and the temperature decline over time. The graphs of the heat release rate per scenario are shown in appendix 6.

Applying fire resistant glass does not have a positive effect on the smoke propagation for adjacent compartments 2 and 4, but does have a positive effect on the smoke propagation to the apartment above and the corridor. The negative effect for compartment 2 and 4 and the positive effect for compartment 8 and 30 are shown in Table 5-6.

Table 5-6. Reducing internal smoke propagation, additional simulations.

	Improvement/reduction			
	Compartment 2*	Compartment 4*	Compartment 8*	Compartment 30*
Scenario 1 – 60 minutes	-199%	-201%	37%	41%
Scenario 2 – 60 minutes	-329%	-336%	50%	65%
Scenario 3 – 60 minutes	-339%	-348%	54%	56%
Scenario 4 – 60 minutes	-512%	-536%	65%	47%

*compartment 2 and 4: adjacent to the fire compartment on the same level; compartment 8: compartment above fire compartment; compartment 30: corridor adjacent to fire compartment.

In all additional simulations the limit for the optical density is exceeded as shown in Figure 5-21, Figure 5-22, Figure 5-23 and Figure 5-24. The optical density in adjacent compartments 2 and 4 exceeds the limit in the same time as the initial scenarios, but exceeds the limit for a longer time.
The optical density in compartments 8 and 30 exceeds the limit in the same time as the initial simulations, but decreases faster. In compartment 8 the optical density decrease to below the limit, while the optical density in compartment 30 decreases from 2.5/m towards the limit of 0,2/m.

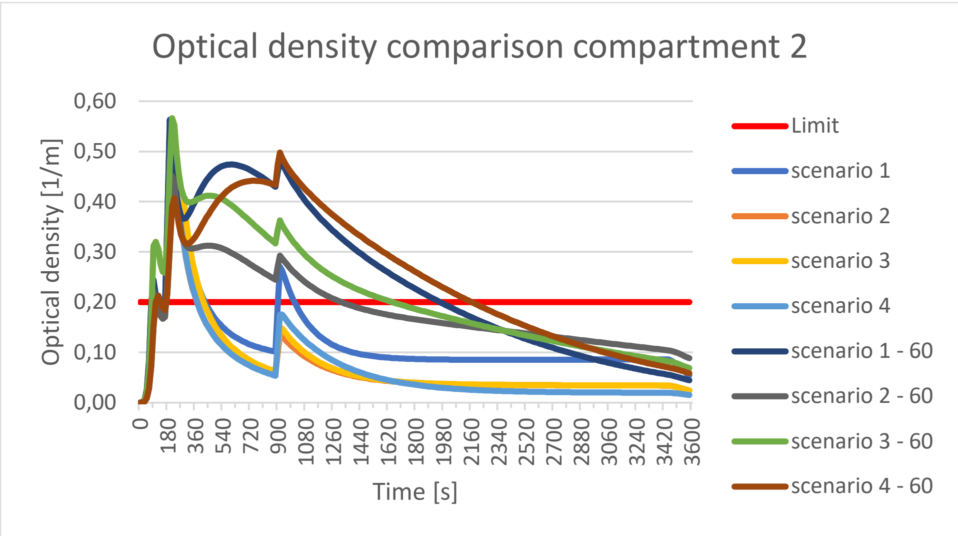

Figure 5-21. Comparison of the optical density for initial and additional scenarios in adjacent compartment 2.

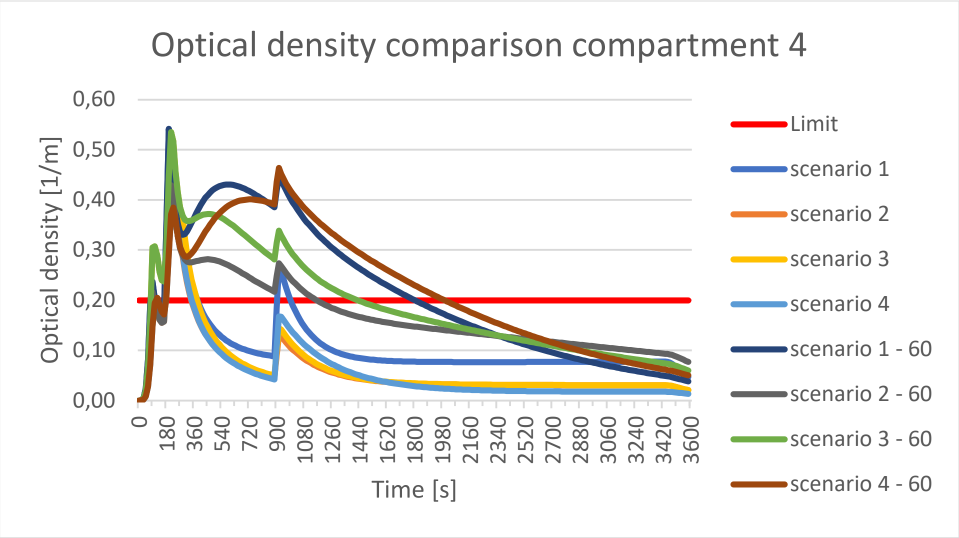

Figure 5-22. Comparison of the optical density for initial and additional scenarios in adjacent compartment 4.

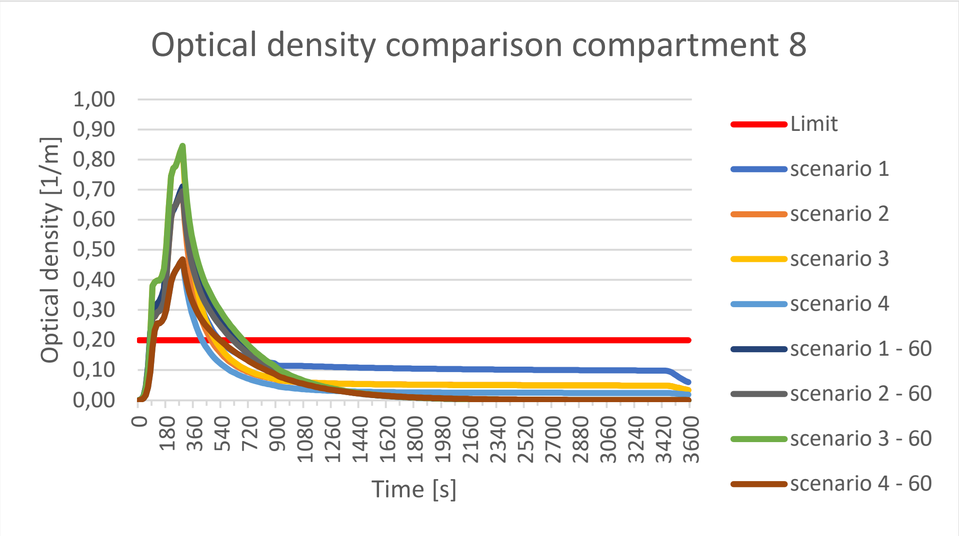

Figure 5-23. Comparison of the optical density for initial and additional scenarios in adjacent compartment 8.

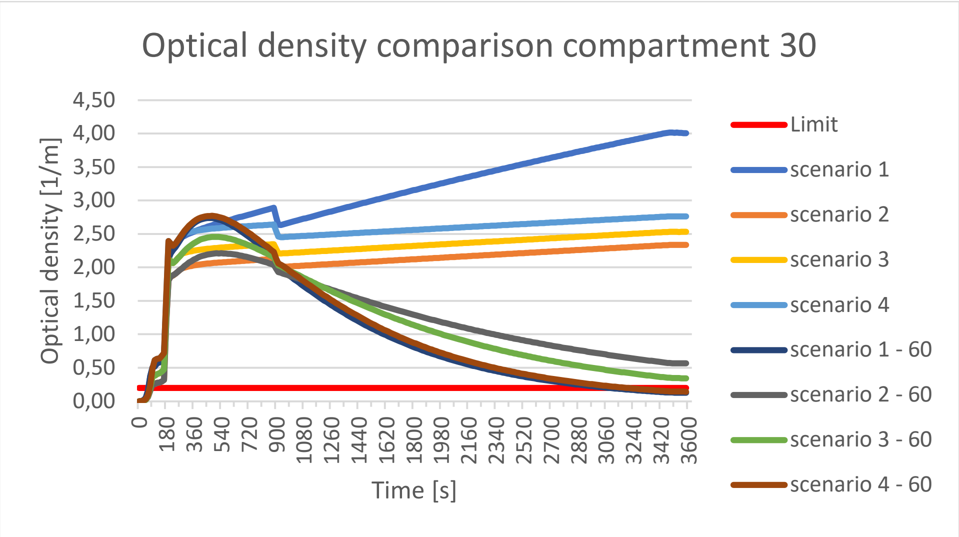

Figure 5-24. Comparison of the optical density for initial and additional scenarios in adjacent compartment 30.

6 Conclusion

This research investigated the possibility of applying a stay-in-place concept in a multi-story residential complex. The effect of the airtightness of inner and outer separation constructions on the smoke propagation has been studied by using numerical simulations. The simulations are based on the drawings of a multi-story residential complex that is going to be build in The Netherlands.

Sub-question 1: How does the stay-in-place concept relate to the Dutch national building code; construction environment decree (2021)?
The stay-in-place concept is not a basic fire safety engineering solution as applicated in the national building decree. However a stay-in-place concept can be applicated in a building by using it as an equivalent solution to the existing fire safety rules. There are a couple of buildings in which the stay-in-place concept has been applied as fire-safety solution.

Sub-question 2: For which buildings/building users is this concept applicable?
A stay-in-place concept is applicable for buildings in where not self reliant building users are living or staying. Self reliant building users can escape a building within the safe egress time, while not self reliant building users can not. Not self reliant building users are mostly situated in hospitals, nursery buildings and apartment buildings.

Sub-question 3: What should be the reliability of the load bearing structure/fire compartmentation/sub-compartmentation for a stay-in-place concept?
The reliability of the loadbearing structure should be improved. The current reliability is 60 minutes, this should be enough when people escape the building but with a stay-in-place concept the reliability should be higher. The needed reliability of fire compartments/sub-compartments depends on the natural fire duration. In the current building code there are no codes regarding the internal airtightness, only for the external airtightness. With a stay-in-place concept there should be codes providing the minimum airtightness needed to fulfil the requirements of a stay-in-place concept.

Sub-question 4: Is it possible to add redundancy to a stay-in-place concept?
The results of the simulation show that the internal airtightness is, related to the external airtightness, not good enough to ensure a stay-in-place concept. Improving the internal and external airtightness has a positive effect on the smoke propagation when the windows in the external separation construction break. However, there is a negative effect on the smoke propagation towards the adjacent compartments when the windows in the external separation construction do not break. Because of this the escape route should still be usable in case of a fire or a balcony needs to be provided.

To what extend can a stay-in-place concept be used in multi-story multi-compartments residential buildings, nursery homes and hospitals?
The biggest danger of a fire in a multi-story residential complex is the spreading of smoke. Reducing the spread of smoke by improving the airtightness of the internal and external separation constructions has a positive effect on the smoke propagation when the windows in the fire compartment break. However this is not enough, the limit for optical density is exceeded in all the adjacent compartments. The spread of smoke is not reduced when the windows in the external separation construction do not break. More smoke is spread to the adjacent compartments. Based on the results of the simulations conducted during this research a stay-in-place concept can not be used in multi-story multi-compartments residential building, nursey homes and hospitals.

7 Perspective view on research

7.1 Reliability

The reliability of the study can be improved, the reliability of the study can be improved by performing a quantitative sensitivity analysis on stochastic boundary conditions, both for the fire and the compartment.. There are limitations with regard to this study methodology and available data. In section 7.2 limitations are stated that where noticed during this research, however more limitations need to be considered. While using temperature and optical density in a specific compartments can be used to determine a stay-in-place concept, it is a simplified way to determine conditions in a compartment are survivable during a fire.

7.2 Limitations

Using CFAST to model and simulate a fire in a compartment and smoke propagation in a building has its limitations. Separation constructions such as walls, floors and ceilings can only be 'constructed' out of one material. Placing of compartments and the airtightness of the separation constructions also have its limitations.

Separation constructions
Separation constructions have their limitations in CFAST. For instance: the façade is cavity wall, from the inside to the outside the wall consists out of gypsum plasterboard, wooden frame with thermal insulation (mineral wool), a cavity and brickwork. In CFAST only one of these layers can be described for the simulation. In this case the gypsum plasterboard. The internal separation constructions between fire compartments is a concrete wall, finished with a stucco. For the calculation only the concrete layer is use. The separation construction between the fire compartment and the hall is a double metal-stud construction with two layers of gypsum plasterboard on both sides. However only one layer can be used for modelling. The ceiling/floor of the compartment consist out of concrete with a finished floor of cement screed. Only the concrete floor is used for the model.

Placing of compartments
The shaft in the building, which is fire compartment of its own, is situated inside the fire compartment. However in order to simulate the model, the shaft had to be placed outside the fire compartment, inside the hallway. The simulation used for this research is build up out of the compartments that are directly connected to the fire compartment. The adjacent compartments on the right and left, the compartment above, the shaft and the corridor are the only modelled compartments. However the smoke can spread further than the directly connected compartment.

Airtightness of separation constructions
The airtightness of separations constructions between compartments needs to be specified for that specific separation construction. This needs to be done by filling in an equivalent surface area for the leakage. In this case, the load bearing elements are concrete walls and floor. Those connections are airtight. The external wall and the wall between the fire compartment and the hall however do have seams through which air or other gasses can leak. The airtightness of the seams connecting the walls can't be modelled as they would be in a building. For the airtightness of the external wall and ceiling/floor connection an equivalent surface area had to be placed in the floor. For the 2 connections a wall had only one equivalent area for airtightness could be specified.

The equivalent surface area used for the airtightness of the construction varies with the pressure. However it is not possible to use this information in CFAST because it does not use pressure as a variable in the entry file for the separation construction. A flow exponent of 0.5 is used, which is a flow exponent for large openings. For seams a flow exponent between 0.5 and 1.0 had to be used. This means that the equivalent surface area should vary depending on the pressure difference between the inside and the outside. Because CFAST does not have an entry file for equivalent surface area based on pressure difference and flow exponents the results of the smoke propagation may differ from a software program which do have an entry file for a pressure dependent equivalent surface area.

During this research the formulas for calculating the equivalent surface have changed a lot. This research is conducted based on the last formulas, which are also used in the NIPV research. The NIPV states that the simulation they made based on this formula do not reflect the test they conducted in their research (Instituut Fysieke veiligheid, 2020).

Fire characteristics
Fire characteristics such as the lower oxygen limit, the heat of combustion and the soot yield and CO yield are based on a fuel controlled fire. However in the additional simulations, the fire was oxygen controlled. Which means that the soot yield and the CO yield could be much higher. In this way smoke production in an oxygen controlled fire is underestimated and the results of the simulations are to positive.

7.3 Improvements

While conducting this research a few subjects passed by that could use some improvements. The limitations as stated in section 7.2 for the separation constructions, the placing of the compartments, the airtightness of separation constructions and the fire characteristics can be improved in a future research into this subject. By improving these limitations the study into this subject can be better conducted. Improvements can also be made into additional fire engineering solutions, such as modelling sprinklers or smoke extraction. Sprinklers have an effect the smoke production and the smoke propagation, smoke extraction has an effect on the smoke propagation in the building. Adding these systems and improving the airtightness of the separation construction at the same time can result in different results for a stay-in-place concept.

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9 Appendices

1. Architectural drawings Amerhorst
2. Qv;10 calculations
3. Input values CFAST model
4. Heat release rate scenario 1 to 4
5. Pressure different scenario 1 to 4
6. Heat release rate additional simulations
7. Optical density additional simulations

1. Architectural drawings Amerhorst

Luchtverversing "overige ruimten"

ventilatie vluchttrappenhuis:
0,5 dm³/s/m²
8,51m²
4,255 dm³/s per etage
22 dm³/s totaal

ventilatie hoofdtrappenhuis:
0,5 dm³/s/m²
14,84 m²
7,42 dm³/s per etage
38 dm³/s totaal

ventilatie lifthal 1:
0,5 dm³/s/m²
18,99 m²
10 dm³/s

ventilatie lifthal 2 + corridor 1 en 2:
0,5 dm³/s/m²
115,05 m²
58 dm³/s

schacht lift:
3,2 dm³/s/m²
4,55 m²
15 dm³/s

schacht beddenlift:
3,2 dm³/s/m²
5,454 m²
18 dm³/s

(gsm)	beldrukker
(gsm)	beldrukker; signaal verzenden naar smartphone
	videofoon
(loos)	geen videofoon toepassen, maar wel alle voorzienningen hier voor aanleggen tot in woning
PL	PasLezer
X	noodontgrendeling
	Codetableau
elleboog	elleboogschakelaar t.b.v. schuifdeur
druk	drukschakelaar t.b.v. schuif- of draaideur
sleutel	sleutelschakelaar t.b.v. schuif- of draaideur
	deur op kleefmagneet
B	vulpunt droge busleiding
	droge blusleiding (door schacht)
	sleutelbuis
30m	brandslanghaspel
P	poederblusser
	deur in vluchtrichting zonder sleutel over de vereisde breedte te openen
	deurdranger
vr.l.	vrijloopdranger gekoppeld aan rookmelder conform NEN 2555 in de woning

Zie tekening
DO-0.01 voor Renvooi

N

Concept
tekening nummer: **DO-1.20**
wijzigingsdatum:
datum: **02-07-2020**

Amerhorst
Amersfoort

onderdeel:
Gebouw A
Begane grond

projectnummer: **2852**
schaal: **1:100**
formaat: **594x841 (A1)**
kenmerk: **2852 Gebouw A.pln**
referte: **Nicole Geertsma, Edo Brunekreef**

opdrachtgever:
Habion, Amaris

SVP
architectuur en stedenbouw
Postbus 465, 3800 AL Amersfoort, 033 470 11 88, www.svp-svp.nl

Luchtverversing "overige ruimten"

ventilatie vluchttrappenhuis:
0,5 dm³/s/m²
8,51m²
4,255 dm³/s per etage
22 dm³/s totaal

ventilatie hoofdtrappenhuis:
0,5 dm³/s/m²
14,84 m²
7,42 dm³/s per etage
38 dm³/s totaal

ventilatie lifthal 1:
0,5 dm³/s/m²
18,99 m²
10 dm³/s

ventilatie lifthal 2 + corridor 1 en 2:
0,5 dm³/s/m²
115,05 m²
58 dm³/s

schacht lift:
3,2 dm³/s/m²
4,55 m²
15 dm³/s

schacht beddenlift:
3,2 dm³/s/m²
5,454 m²
18 dm³/s

- beldrukker
- (gsm) beldrukker; signaal verzenden naar smartphone
- videofoon
- (loos) geen videofoon toepassen, maar wel alle voorzienningen hier voor aanleggen tot in woning
- PL — PasLezer
- X — noodontgrendeling
- Codetableau
- elleboog — elleboogschakelaar t.b.v. schuifdeur
- druk — drukschakelaar t.b.v. schuif- of draaideur
- sleutel — sleutelschakelaar t.b.v. schuif- of draaideur
- deur op kleefmagneet
- B — vulpunt droge busleiding
- droge blusleiding (door schacht)
- sleutelbuis
- 30m — brandslanghaspel
- P — poederblusser
- $ — deur in vluchtrichting zonder sleutel over de vereisde breedte te openen
- deurdranger
- vr.l. — vrijloopdranger gekoppeld aan rookmelder conform NEN 2555 in de woning

Zie tekening
DO-0.01 voor Renvooi

N

Concept

tekening nummer: **DO-1.21**

wijzigingsdatum:

datum: **02-07-2020**

Amerhorst
Amersfoort

onderdeel:

Gebouw A
Verdieping 1 t/m 3

projectnummer: **2852**

schaal: **1:100**

formaat: **594x841 (A1)**

kenmerk: **2852 Gebouw A.pln**

referte: **Nicole Geertsma, Edo Brunekreef**

opdrachtgever:

Habion, Amaris

SVP
architectuur en stedenbouw
Postbus 465, 3800 AL Amersfoort, 033 470 11 88, www.svp-svp.nl

Luchtverversing "overige ruimten"

ventilatie vluchttrappenhuis:
0,5 dm³/s/m²
8,51m²
4,255 dm³/s per etage
22 dm³/s totaal

ventilatie hoofdtrappenhuis:
0,5 dm³/s/m²
14,84 m²
7,42 dm³/s per etage
38 dm³/s totaal

ventilatie lifthal 1:
0,5 dm³/s/m²
18,99 m²
10 dm³/s

ventilatie lifthal 2 + corridor 1 en 2:
0,5 dm³/s/m²
115,05 m²
58 dm³/s

schacht lift:
3,2 dm³/s/m²
4,55 m²
15 dm³/s

schacht beddenlift:
3,2 dm³/s/m²
5,454 m²
18 dm³/s

beldrukker
(gsm) beldrukker; signaal verzenden naar smartphone
videofoon
(loos) geen videofoon toepassen, maar wel alle voorzienningen hier voor aanleggen tot in woning
PL PasLezer
X noodontgrendeling
Codetableau
elleboog elleboogschakelaar t.b.v. schuifdeur
druk drukschakelaar t.b.v. schuif- of draaideur
sleutel sleutelschakelaar t.b.v. schuif- of draaideur
deur op kleefmagneet
B vulpunt droge busleiding
droge blusleiding (door schacht)
sleutelbuis
30m brandslanghaspel
P poederblusser
deur in vluchtrichting zonder sleutel over de vereisde breedte te openen
deurdranger
vr.l. vrijloopdranger gekoppeld aan rookmelder conform NEN 2555 in de woning

Zie tekening DO-0.01 voor Renvooi

N

Concept
tekening nummer: **DO-1.22**
wijzigingsdatum:
datum: **02-07-2020**

Amerhorst
Amersfoort

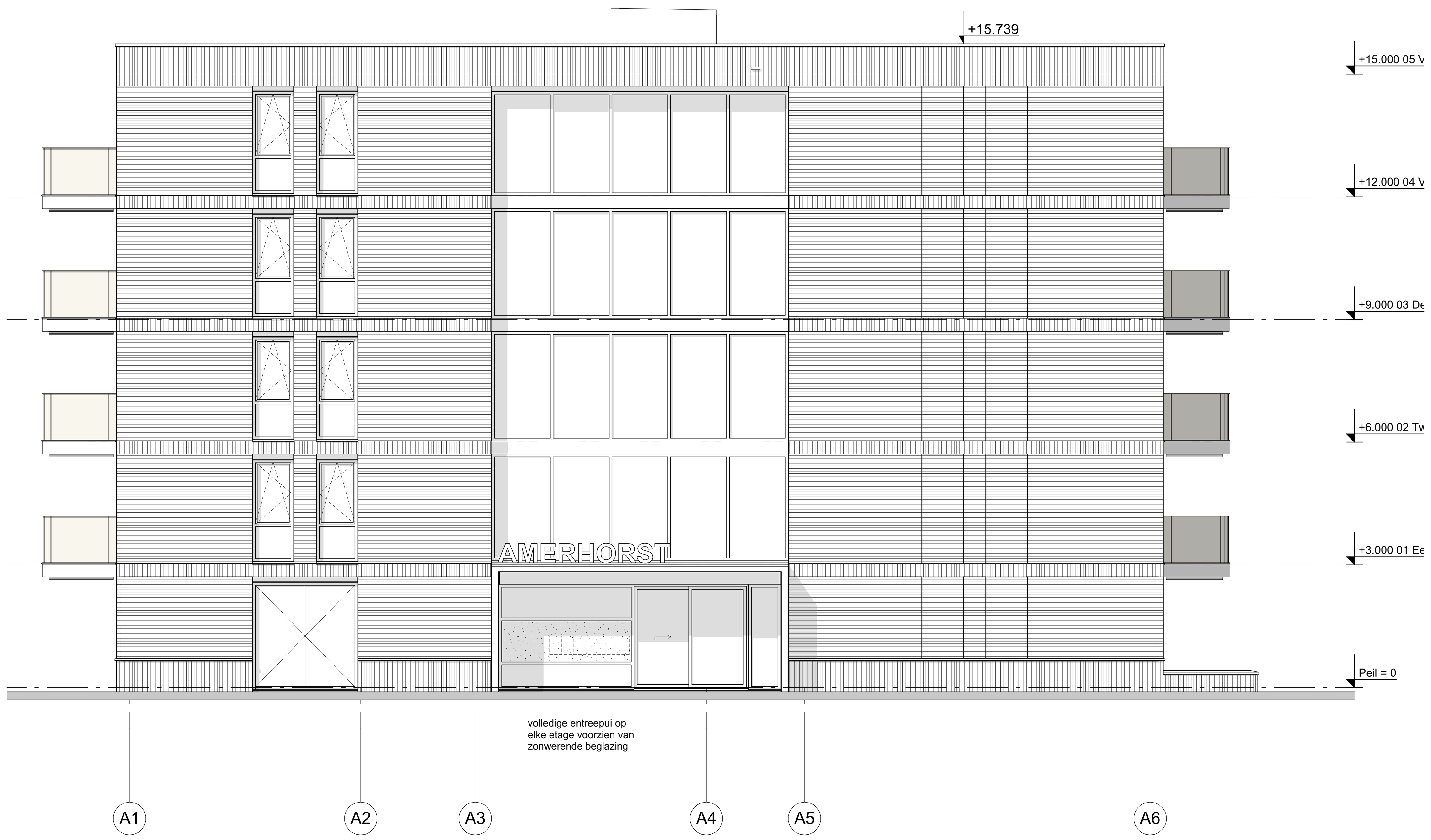
onderdeel:
Gebouw A
Verdieping 4

projectnummer: **2852**
schaal: **1:100**
formaat: **594x841 (A1)**
kenmerk: **2852 Gebouw A.pln**
referte: **Nicole Geertsma, Edo Brunekreef**

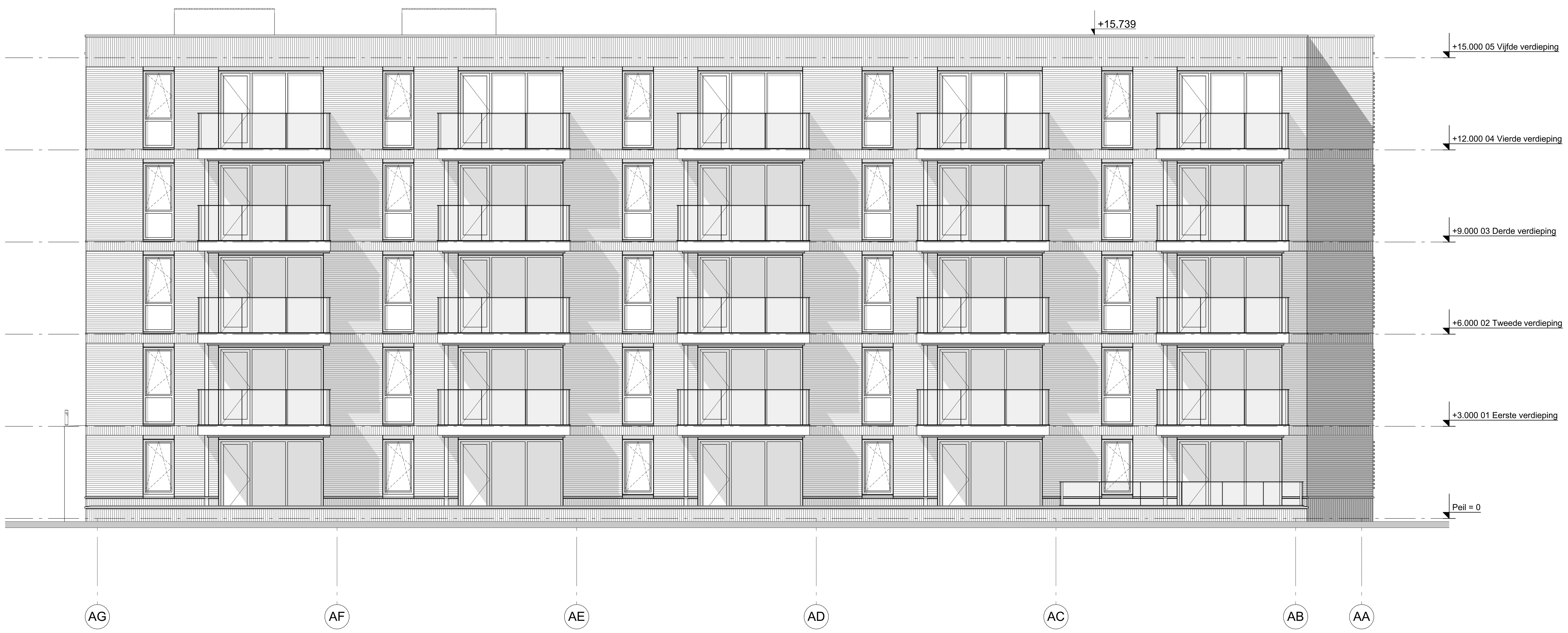
opdrachtgever:
Habion, Amaris

SVP
architectuur en stedenbouw

Postbus 465, 3800 AL Amersfoort, 033 470 11 88, www.svp-svp.nl



Zuidgevel



Oostgevel

Concept
tekening nummer: **DO-1.30**
wijzigingsdatum:
datum: **02-07-2020**

Amerhorst
Amersfoort

onderdeel:
Gebouw A
Oost- en Zuidgevel

projectnummer: **2852**
schaal: **1:100**
formaat: **594x841 (A1)**
kenmerk: **2852 Gebouw A.pln**
referte: **Nicole Geertsma, Edo Brunekreef**

opdrachtgever:
Habion, Amaris

SVP
architectuur en stedenbouw

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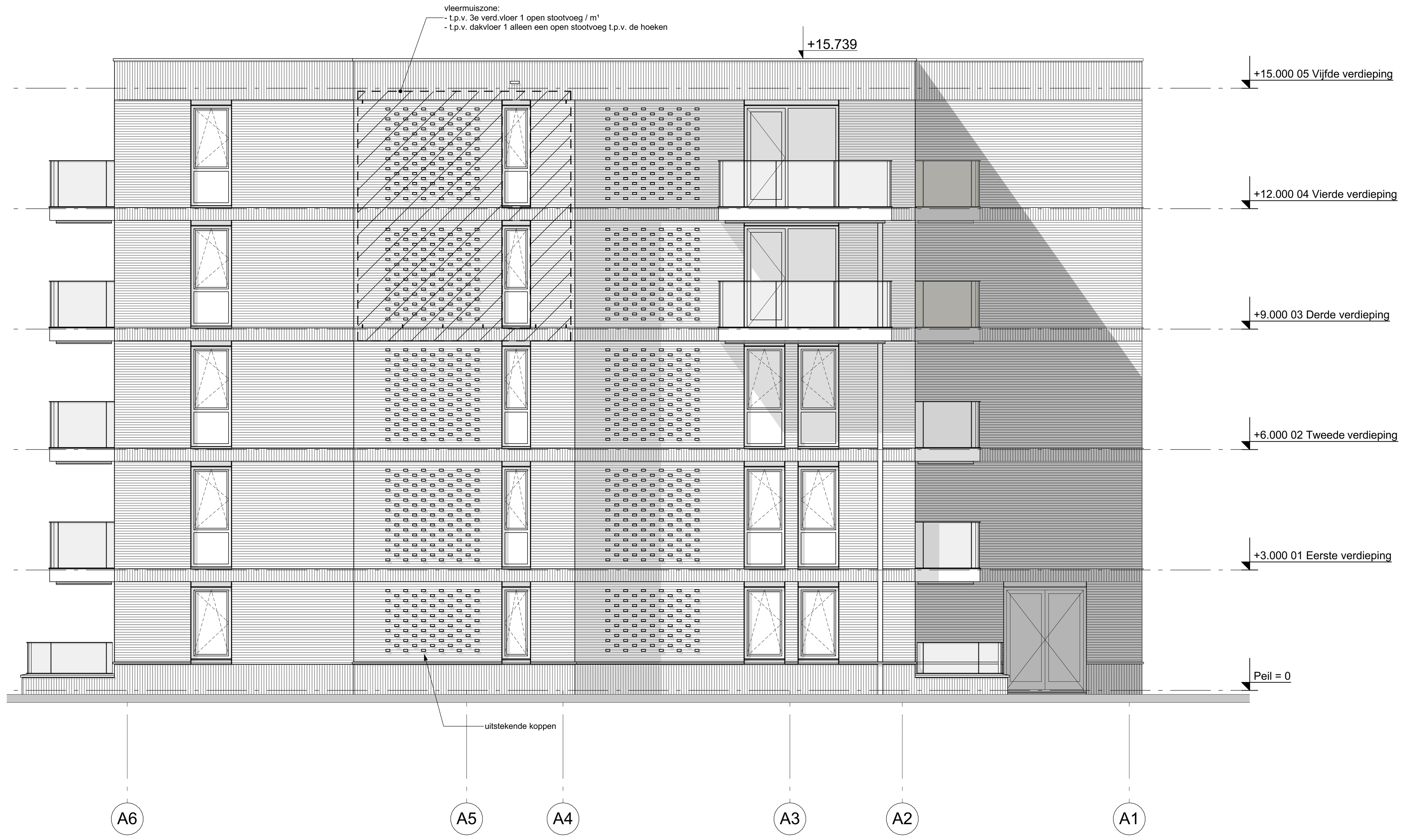

Noordgevel

Westgevel

Concept

tekening nummer: **DO-1.31**

wijzigingsdatum:

datum: **02-07-2020**

Amerhorst
Amersfoort

onderdeel:

Gebouw A
Noord- en Westgevel

projectnummer: **2852**

schaal: **1:100**

formaat: **594x841 (A1)**

kenmerk: **2852 Gebouw A.pln**

referte: **Nicole Geertsma, Edo Brunekreef**

opdrachtgever:

Habion, Amaris

SVP
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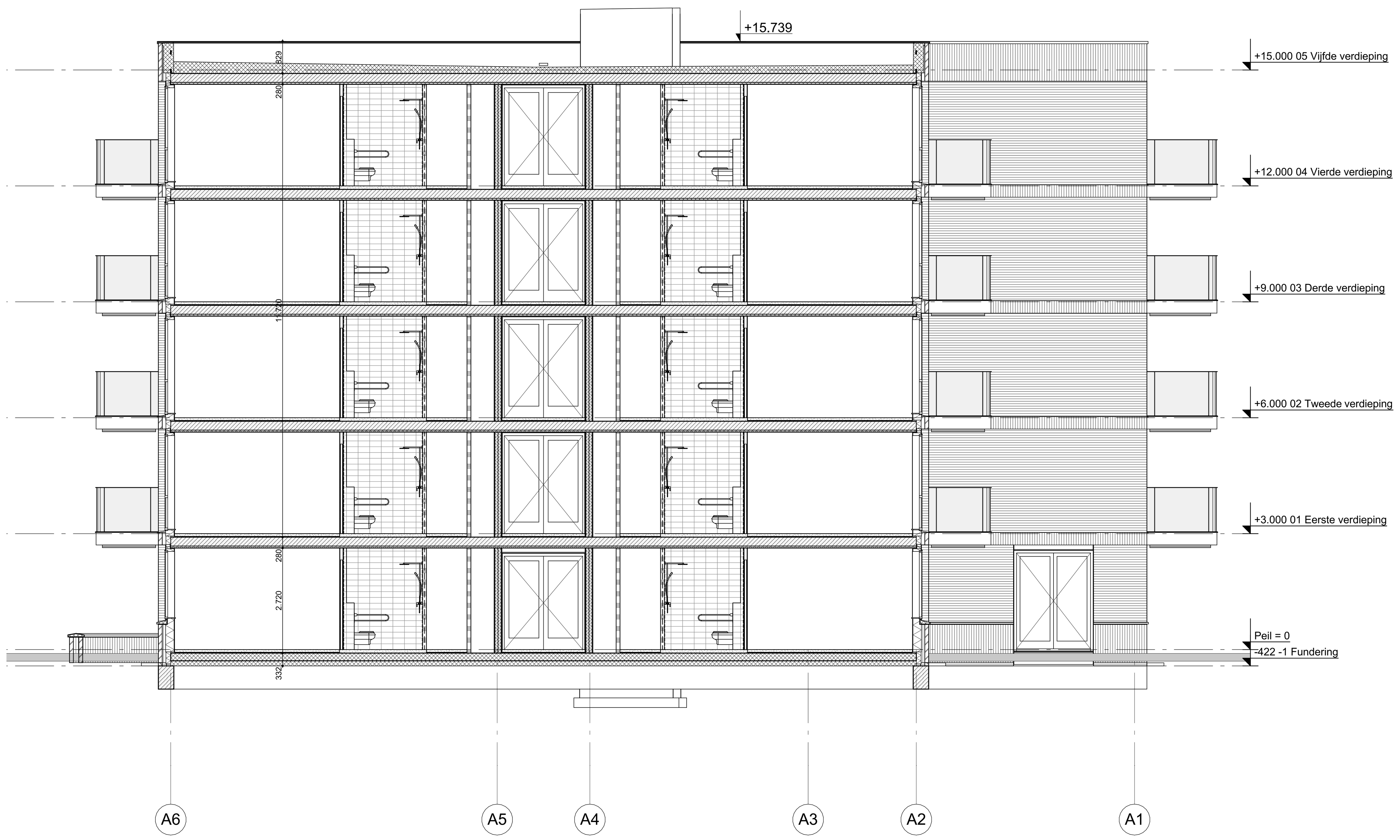
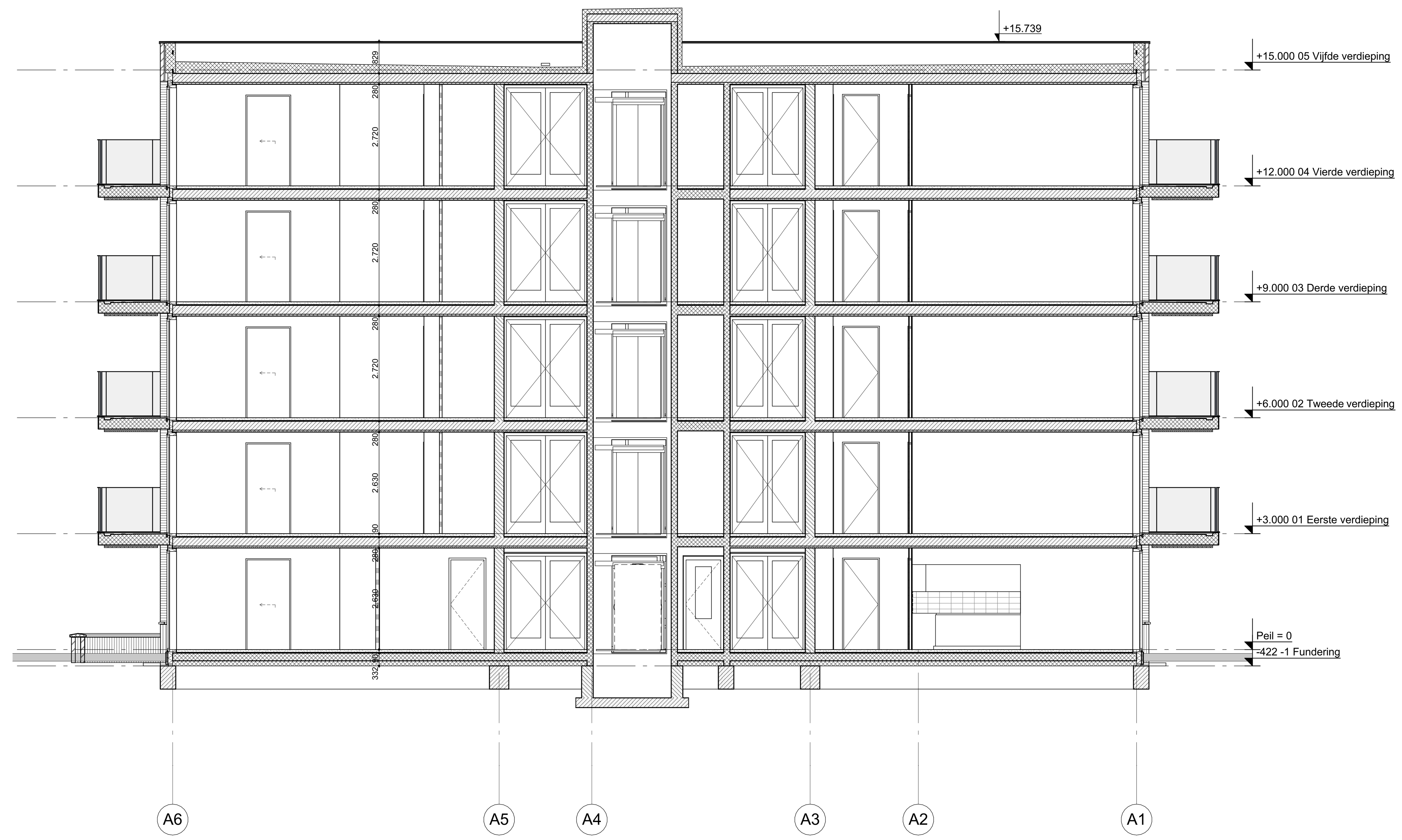


Doorsnede A-A



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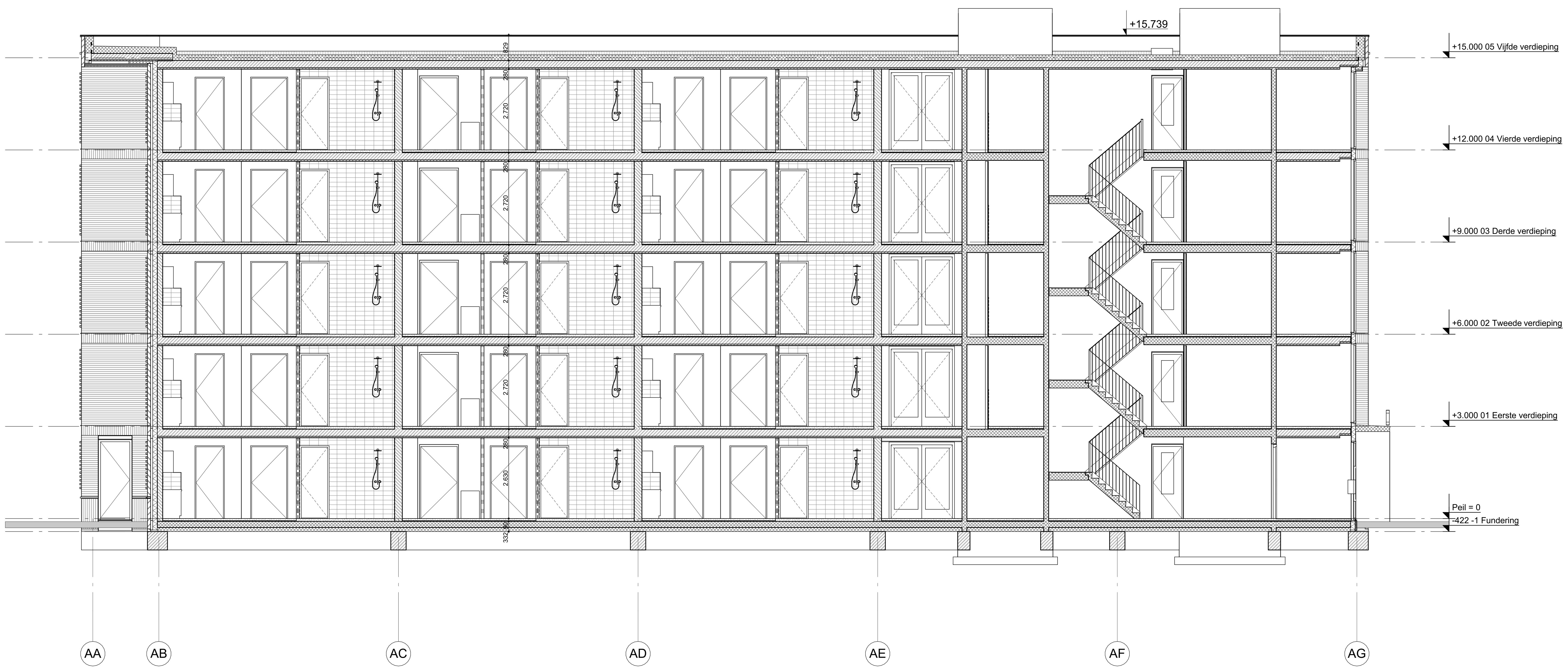


Doorsnede C-C

Concept
tekening nummer: **DO-1.32**
wijzigingsdatum:
datum: **02-07-2020**

Amerhorst
Amersfoort

onderdeel:
Gebouw A
Doorsnede A, B en C

projectnummer: **2852**
schaal: **1:100**
formaat: **594x841 (A1)**
kenmerk: **2852 Gebouw A.pln**
referte: **Nicole Geertsma, Edo Brunekreef**

opdrachtgever:
Habion, Amaris

SVP
architectuur en stedenbouw

Postbus 465, 3800 AL Amersfoort, 033 470 11 88, www.svp-svp.nl

2. Qv;10 calculations

Scenario 1 **Qv;10 in $dm^3/s*m^2$: external 0.45 - internal 1.35**

Separation construction	Qv;10 [dm3/s]	Qv;10 [$dm^3/s*m^2$]	Aequivalent [dm^2]	Aequivalent [m^2]	Height [m]	Vent width [m]
Façade	28,125	0,45	1,06770	0,01068	2,85	0,00375
Floor	21,094	1,35	0,80077	0,00801	2,85	0,00281
Ceiling	21,094	1,35	0,80077	0,00801	2,85	0,00281
Door in separation construction		-	0,21090	0,00211	2,85	0,00074
construction corridor		1,35	2,99218	0,02992	2,85	0,01050
leakage area shaft				0,00600	0,06	0,10000
Separation construction corridor	84,375	1,35	3,20309	0,02603	2,85	0,00913
Separation construction 1	21,094	1,35	0,80077	0,00801	2,85	0,00281
Separation construction 2	21,094	1,35	0,80077	0,00801	2,85	0,00281

Scenario 2 **Qv;10 in $dm^3/s*m^2$: external 0.45 - internal 0.45**

Separation construction	Qv;10 [dm3/s]	Qv;10 [$dm^3/s*m^2$]	Aequivalent [dm^2]	Aequivalent [m^2]	Height [m]	Vent width [m]
Façade	28,125	0,45	1,06770	0,01068	2,85	0,00375
Floor	7,031	0,45	0,26692	0,00267	2,85	0,00094
Ceiling	7,031	0,45	0,26692	0,00267	2,85	0,00094
Door in separation construction		-	0,21090	0,00211	2,85	0,00074
construction corridor		0,45	0,85679	0,00857	2,85	0,00301
leakage area shaft				0,00600	0,06	0,10000
Separation construction corridor	28,125	0,45	0,85679	0,00468	2,85	0,00164
Separation construction 1	7,031	0,45	0,26692	0,00267	2,85	0,00094
Separation construction 2	7,031	0,45	0,26692	0,00267	2,85	0,00094

Scenario 3 **Qv;10 in $dm^3/s*m^2$: external 0.15 - internal 0.45**

Separation construction	Qv;10 [dm3/s]	Qv;10 [$dm^3/s*m^2$]	Aequivalent [dm^2]	Aequivalent [m^2]	Height [m]	Vent width [m]
Façade	9,375	0,15	0,35590	0,00356	2,85	0,00125
Floor	7,031	0,45	0,26692	0,00267	2,85	0,00094
Ceiling	7,031	0,45	0,26692	0,00267	2,85	0,00094
Door in separation construction		-	0,21090	0,00211	2,85	0,00074
construction corridor		0,45	0,85679	0,00857	2,85	0,00301
leakage area shaft				0,00600	0,06	0,10000
Separation construction corridor	28,125	0,45	0,85679	0,00468	2,85	0,00164
Separation construction 1	7,031	0,45	0,26692	0,00267	2,85	0,00094
Separation construction 2	7,031	0,45	0,26692	0,00267	2,85	0,00094

Scenario 4 **Qv;10 in $dm^3/s*m^2$: external 0.15 - internal 0.15**

Separation construction	Qv;10 [dm3/s]	Qv;10 [$dm^3/s*m^2$]	Aequivalent [dm^2]	Aequivalent [m^2]	Height [m]	Vent width [m]
Façade	9,375	0,15	0,35590	0,00356	2,85	0,00125
Floor	2,344	0,15	0,08897	0,00089	2,85	0,00031
Ceiling	2,344	0,15	0,08897	0,00089	2,85	0,00031
Door in separation construction		-	0,21090	0,00211	2,85	0,00074
construction corridor		0,15	0,14500	0,00145	2,85	0,00051
leakage area shaft				0,00600	0,06	0,10000
Separation construction corridor	9,375	0,15	0,14500	0,00468	2,85	0,00164
Separation construction 1	2,344	0,15	0,08897	0,00089	2,85	0,00031
Separation construction 2	2,344	0,15	0,08897	0,00089	2,85	0,00031

3. Input values CFAST model

CFAST

Release Version : CFAST 7.7.2
Revision : CFAST7.7.2-2-gb5b46f68
Revision Date : Fri Nov 5 10:47:09 2021 -0400
Compilation Date : Sun 11/07/2021 11:00 AM

Data file: C:\Users\joost\Desktop\C-fast models\2022-06-24\Scenario_1_0.45_1.35.in
Title: CFAST Simulation

OVERVIEW

Compartments	Doors, ...	Ceil. Vents, ...	MV Connects
19	34	3	0

Simulation Time (s)	Output Interval (s)	Smokeview Interval (s)	Spreadsheet Interval (s)
3600.00	60.00	15.00	15.00

AMBIENT CONDITIONS

Interior Temperature (C)	Interior Pressure (Pa)	Exterior Temperature (C)	Exterior Pressure (Pa)
20.	101325.	20.	101325.

THERMAL PROPERTIES

Name	Conductivity (kW/(m °C))	Specific Heat (kJ/(m °C))	Density (kg/m^3)	Thickness (m)	Emissivity
CONCRETE	1.75	1.000E+03	2.200E+03	0.150	0.940
GYP1/2	0.160	900.	790.	1.300E-02	0.900
DEFAULT	0.120	900.	800.	1.200E-02	0.900

COMPARTMENTS

Compartment	Name	Width (m)	Depth (m)	Height (m)	Floor Height (m)	Ceiling Height (m)	Shaft	Hall	Wall Leakage (m^2)	Floor Leakage (m^2)
1	Comp 1	7.80	8.45	3.00	0.00	3.00	*		0.0	0.0
2	Comp 3	7.80	8.45	3.00	0.00	3.00			0.0	0.0
3	Comp 4	7.80	8.45	3.00	0.00	3.00	*		0.0	0.0
4	Comp 2	7.80	8.45	3.00	0.00	3.00	*		0.0	0.0
5	Comp 5	7.80	8.45	3.00	0.00	3.00	*		0.0	0.0
6	Comp 6	7.80	8.45	3.00	3.00	6.00	*		0.0	0.0
7	Comp 16	2.20	0.60	9.00	0.00	9.00	*		0.0	0.0
8	Comp 7	7.80	8.45	3.00	3.00	6.00	*		0.0	0.0
9	Comp 8	7.80	8.45	3.00	3.00	6.00	*		0.0	0.0
10	Comp 9	7.80	8.45	3.00	3.00	6.00	*		0.0	0.0
11	Comp 10	7.80	8.45	3.00	3.00	6.00	*		0.0	0.0
12	Comp 11	7.80	8.45	3.00	6.00	9.00	*		0.0	0.0
13	Comp 12	7.80	8.45	3.00	6.00	9.00	*		0.0	0.0
14	Comp 13	7.80	8.45	3.00	6.00	9.00	*		0.0	0.0
15	Comp 14	7.80	8.45	3.00	6.00	9.00	*		0.0	0.0
16	Comp 15	7.80	8.45	3.00	6.00	9.00	*		0.0	0.0
17	Comp 30	39.00	2.40	3.00	0.00	3.00	*		0.0	0.0
18	Comp 31	39.00	2.40	3.00	3.00	6.00	*		0.0	0.0
19	Comp 32	39.00	2.40	3.00	6.00	9.00	*		0.0	0.0

COMPARTMENT MATERIALS

Compartment	Name	Surface	Layer	Conductivity (kW/(m °C))	Specific Heat (kJ/(m °C))	Density (kg/m^3)	Thickness (m)	Emissivity	Material
1	Comp 1	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
2	Comp 3	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
3	Comp 4	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE

		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
4	Comp 2	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
5	Comp 5	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
6	Comp 6	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
7	Comp 16	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
8	Comp 7	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
9	Comp 8	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
10	Comp 9	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
11	Comp 10	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
12	Comp 11	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
13	Comp 12	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
14	Comp 13	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
15	Comp 14	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
16	Comp 15	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
17	Comp 30	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2

18	Comp 31	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2
19	Comp 32	Ceiling	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE
		Walls	1	0.160	900.	790.	1.300E-02	0.900	GYP1/2

VENT CONNECTIONS

Wall Vents (Doors, Windows, ...)

From Compartment	To Compartment	Vent Number	Width (m)	Sill Height (m)	Soffit Height (m)	Open/Close Type (m)	Trigger Value (C/W/m^2)	Target	Initial Time (s)	Initial Fraction	Final Time (s)	Final Fraction
Comp 2	Outside	1	3.35	0.00	2.54	Time			0.00	1.00		
Comp 2	Outside	2	0.94	0.80	2.54	Time			0.00	0.00	300.00	0.00
Comp 3	Outside	3	3.35	0.00	2.54	RAMP # 1						
Comp 3	Outside	4	0.94	0.80	2.54	RAMP # 2						
Comp 4	Outside	5	3.35	0.00	2.54	Time			0.00	1.00		
Comp 4	Outside	6	0.94	0.80	2.54	Time			0.00	1.00		
Comp 7	Outside	7	3.35	0.00	2.54	Time			0.00	1.00		
Comp 7	Outside	8	0.94	0.80	2.54	Time			0.00	1.00		
Comp 8	Outside	9	3.35	0.00	2.54	RAMP # 3						
Comp 8	Outside	10	0.94	0.80	2.54	RAMP # 4						
Comp 9	Outside	11	3.35	0.00	2.54	Time			0.00	1.00		
Comp 9	Outside	12	0.94	0.80	2.54	Time			0.00	1.00		
Comp 13	Outside	13	3.35	0.00	2.54	Time			0.00	1.00		
Comp 13	Outside	14	0.94	0.80	2.54	Time			0.00	1.00		
Comp 3	Comp 30	15	1.26	0.00	2.40	RAMP # 5						
Comp 3	Comp 16	16	0.10	2.50	2.56	Time			0.00	1.00	0.00	0.00
Comp 16	Comp 8	17	0.10	5.50	5.56	Time			0.00	1.00	0.00	0.00
Comp 16	Comp 13	18	0.10	8.50	8.56	Time			0.00	1.00	0.00	0.00
Comp 3	Outside	19	0.00	0.00	2.85	Time			0.00	1.00	3600.00	1.00

Comp 3	Comp 2	20	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 3	Comp 4	21	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 3	Comp 30	22	0.01	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 8	Comp 31	23	0.01	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 2	Outside	24	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 4	Outside	25	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 2	Comp 30	26	1.26	0.00	2.40	RAMP # 6					
Comp 4	Comp 30	27	1.26	0.00	2.40	RAMP # 7					
Comp 8	Comp 31	28	1.26	0.00	2.40	RAMP # 8					
Comp 2	Comp 30	29	0.01	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 4	Comp 30	30	0.01	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 8	Outside	31	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 13	Outside	32	0.00	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 13	Comp 32	33	0.01	0.00	2.85	Time		0.00	1.00	3600.00	1.00
Comp 13	Comp 32	34	1.26	0.00	2.40	Time		0.00	1.00		

Ceiling and Floor Vents

Top Compartment	Bottom Compartment	Vent Number	Shape	Area (m^2)	Open/Close Type	Trigger Value (C/W/m^2)	Target	Initial Time (s)	Initial Fraction	Final Time (s)	Final Fraction
Outside	Comp 16	1	Square	0.06	Time			0.00	1.00	0.00	1.00
Comp 8	Comp 3	2	Square	0.01	Time			0.00	1.00	0.00	1.00
Comp 13	Comp 8	3	Square	0.01	Time			0.00	1.00	0.00	1.00

There are no mechanical flow connections

VENT RAMPS

Type	From Compartment	To Compartment	Vent Number		(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)
H	Comp 3	Outside	1	Time	0	299	300	3600						
				Fraction	0.00	0.00	1.00	1.00						
H	Comp 3	Outside	2	Time	0	299	300	3600						
				Fraction	0.00	0.00	1.00	1.00						
H	Comp 8	Outside	3	Time	0	299	300							
				Fraction	0.00	0.00	1.00							
H	Comp 8	Outside	4	Time	0	299	300							
				Fraction	0.00	0.00	1.00							
H	Comp 3	Comp 30	5	Time	0	180	181	211	212	3600				
				Fraction	0.00	0.00	1.00	1.00	0.00	0.00				
H	Comp 2	Comp 30	6	Time	0	900	901	931	932					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Comp 4	Comp 30	7	Time	0	900	901	931	932					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Comp 8	Comp 31	8	Time	0	900	901	931	932					
				Fraction	0.00	0.00	1.00	1.00	0.00					

FIRES

Name: New Fire 2   Referenced as object # 1 Normal fire

Compartment	Fire Type	Time to Flaming	Position (x,y,z)			Relative Humidity	Lower O2 Limit	Radiative Fraction
Comp 3	Constrained	0.0	3.90	4.22	0.00	50.0	10.00	0.35

Chemical formula of the fuel

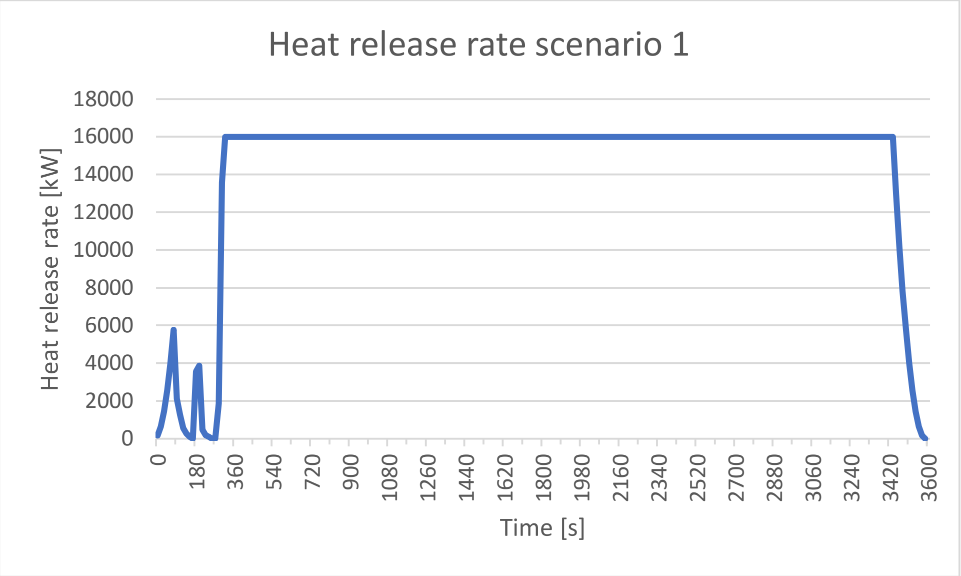
Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
4.000	6.000	3.000	0.000	0.000

Time (s)	Mdot (kg/s)	Hcomb (J/kg)	Qdot (W)	Zoffset (m)	Soot (kg/kg)	CO (kg/kg)	HCN (kg/kg)	HCl (kg/kg)	TS (kg/kg)

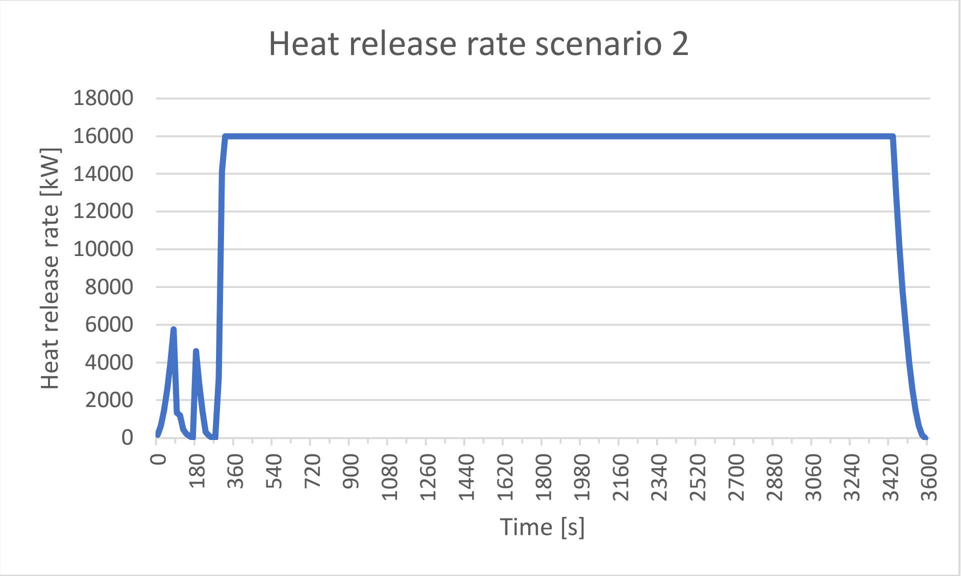
0.	0.0	1.75E+07	0.0	0.0	1.00E-02	1.04E-02	0.0	0.0	0.0
15.	9.14E-03	1.75E+07	1.60E+05	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
30.	3.66E-02	1.75E+07	6.40E+05	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
45.	8.23E-02	1.75E+07	1.44E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
60.	0.15	1.75E+07	2.56E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
75.	0.23	1.75E+07	4.00E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
90.	0.33	1.75E+07	5.76E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
105.	0.45	1.75E+07	7.84E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
120.	0.59	1.75E+07	1.02E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
135.	0.74	1.75E+07	1.30E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
150.	0.91	1.75E+07	1.60E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3450.	0.91	1.75E+07	1.60E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3465.	0.74	1.75E+07	1.30E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3480.	0.59	1.75E+07	1.02E+07	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3495.	0.45	1.75E+07	7.84E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3510.	0.33	1.75E+07	5.76E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3525.	0.23	1.75E+07	4.00E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3540.	0.15	1.75E+07	2.56E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3555.	8.23E-02	1.75E+07	1.44E+06	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3570.	3.66E-02	1.75E+07	6.40E+05	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3585.	9.14E-03	1.75E+07	1.60E+05	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3600.	0.0	1.75E+07	0.0	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0
3610.	0.0	1.75E+07	0.0	0.0	2.64E-02	1.04E-02	0.0	0.0	0.0

4. Heat release rate scenario 1 to 4

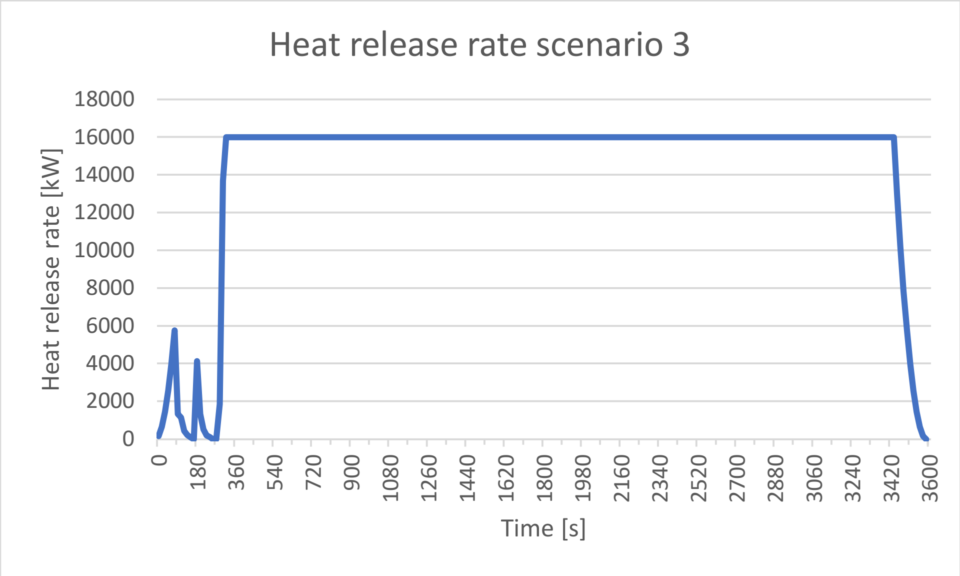
Scenario 1



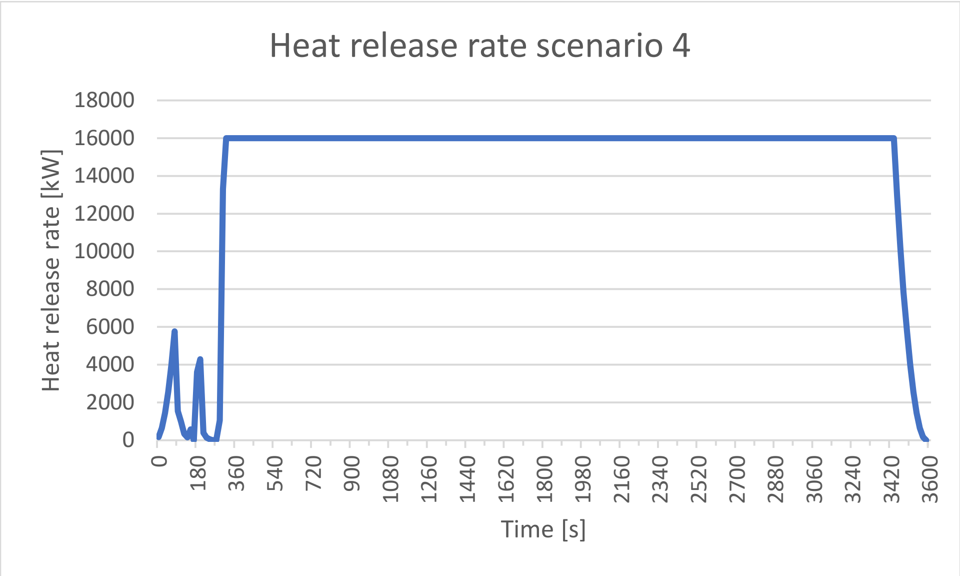
Scenario 2



Scenario 3

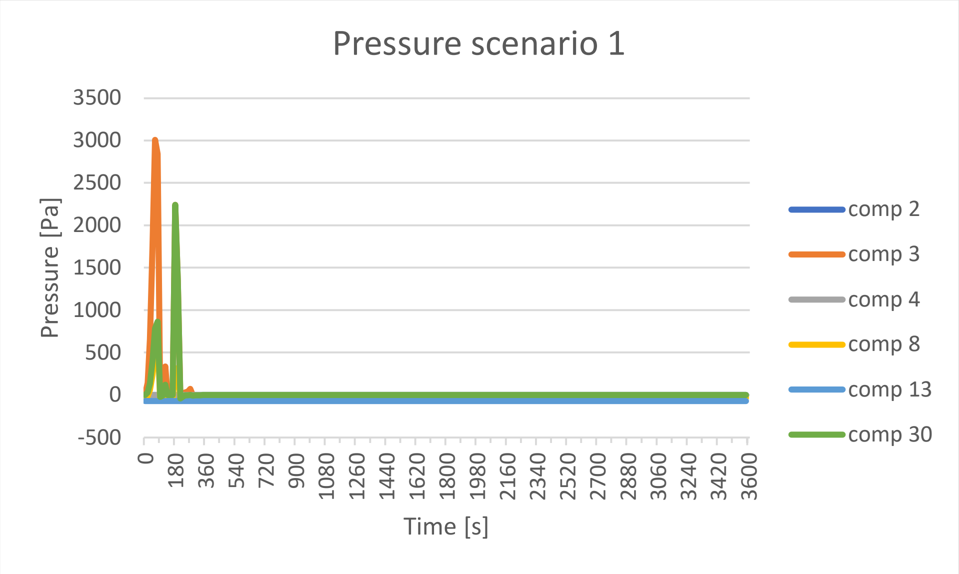


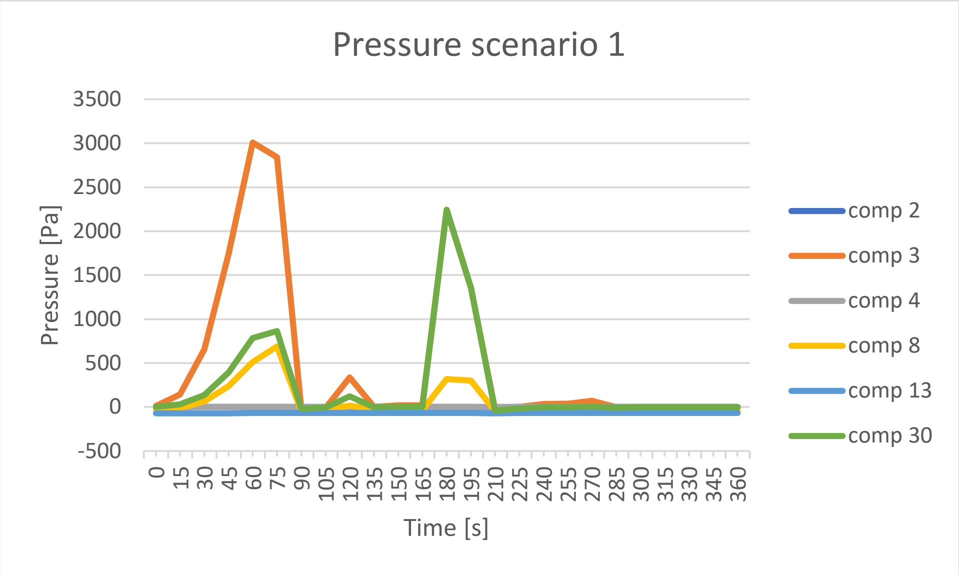
Scenario 4



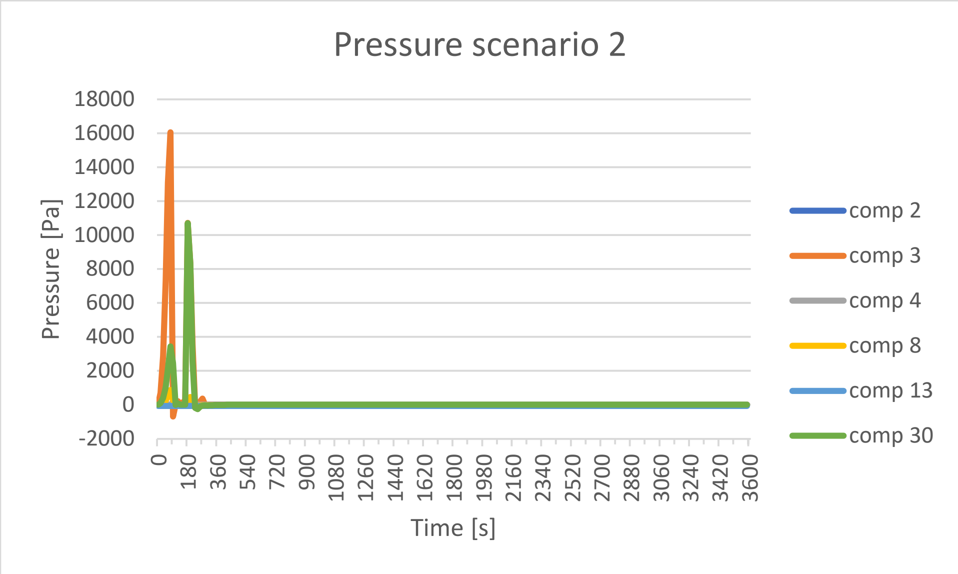
5. Pressure difference scenario 1 to 4

Scenario 1

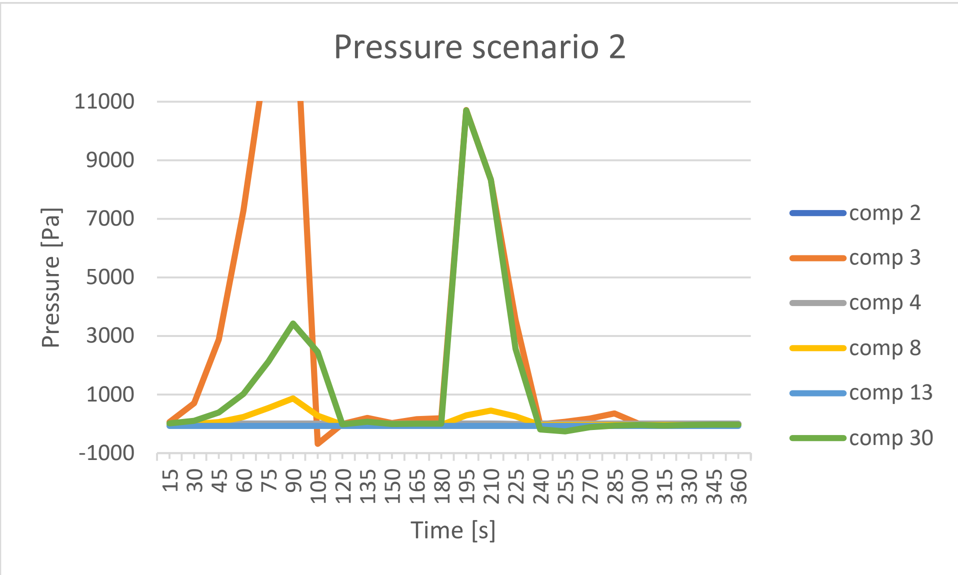




Scenario 2

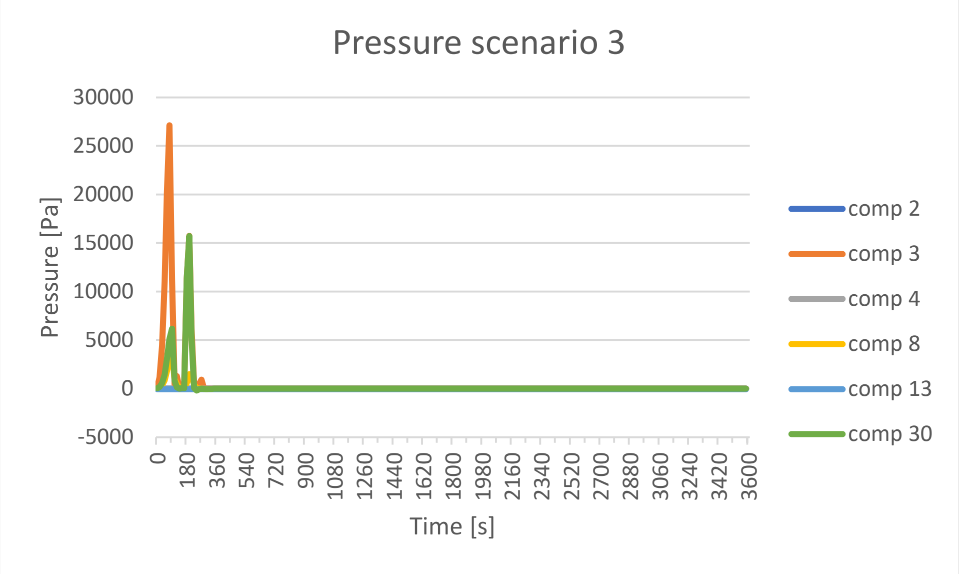


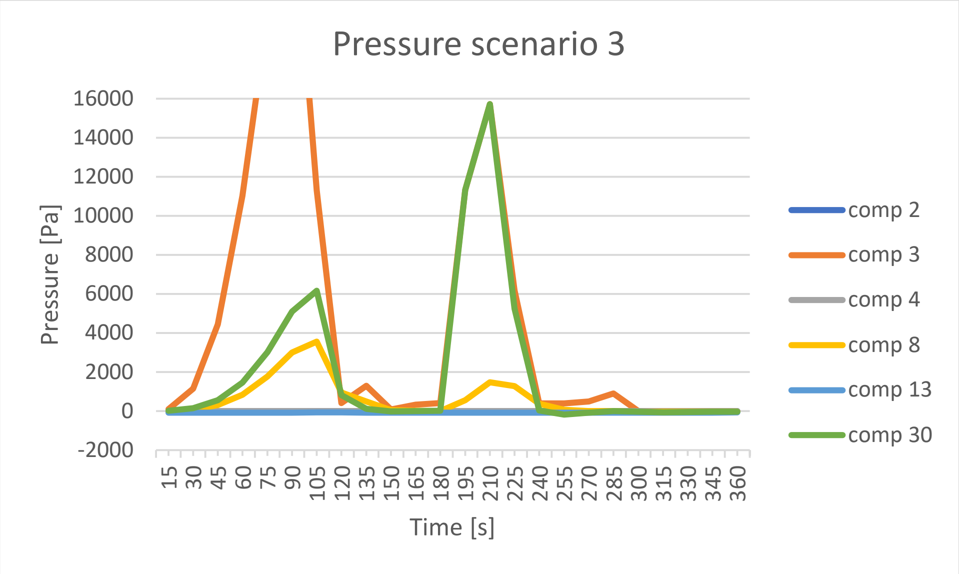
Pressure scenario 2
Pressure [Pa]
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
2160
2340
2520
2700
2880
3060
3240
3420
3600
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30



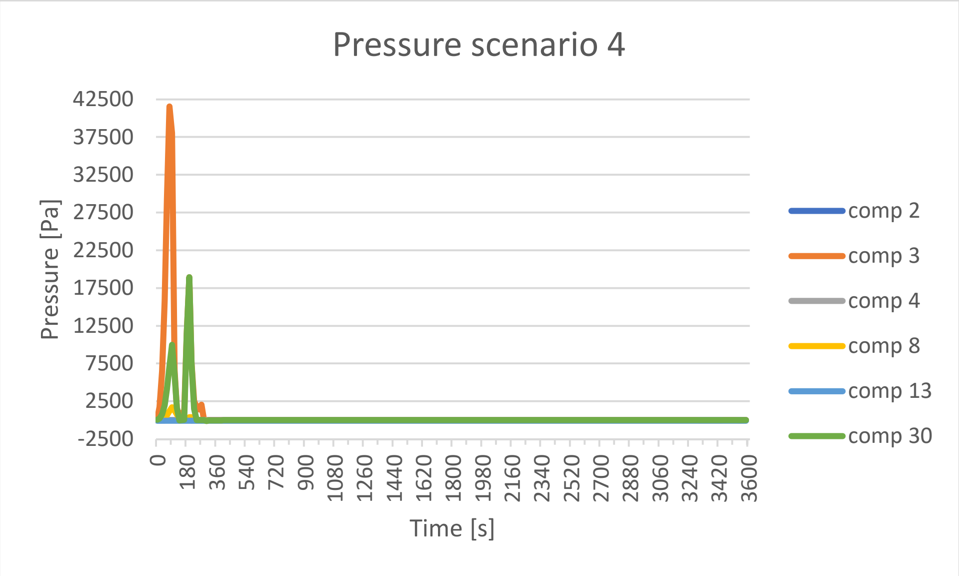
Pressure scenario 2
Pressure [Pa]
11000
9000
7000
5000
3000
1000
-1000
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30

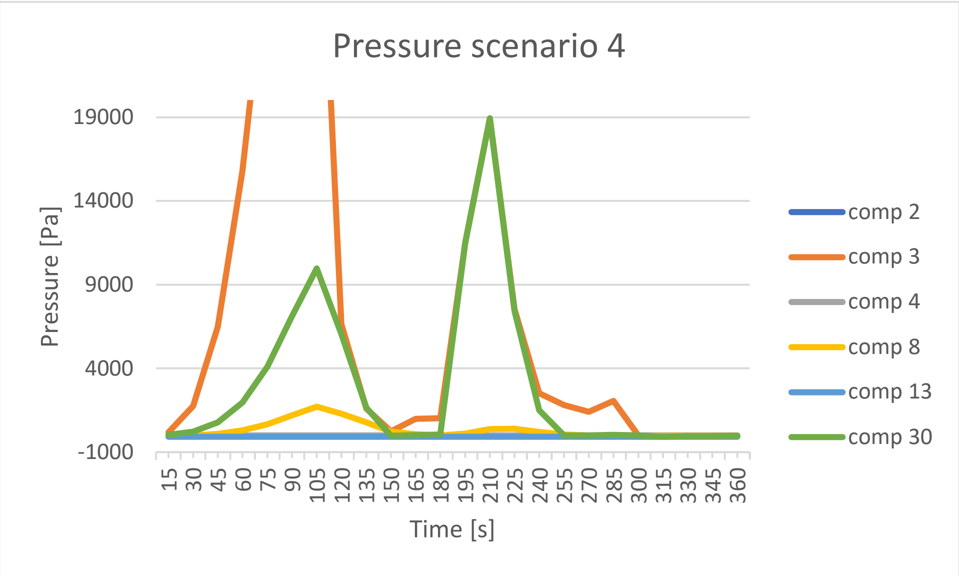
Scenario 3


Pressure scenario 3
30000
25000
20000
15000
10000
5000
0
-5000
Pressure [Pa]
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
2160
2340
2520
2700
2880
3060
3240
3420
3600
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30


Pressure scenario 3
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
Pressure [Pa]
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30

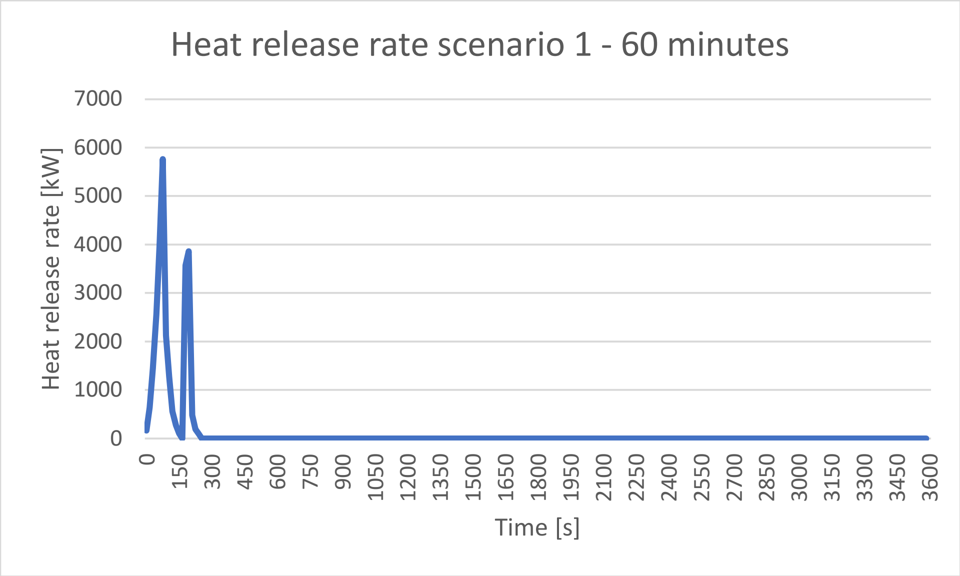
Scenario 4


Pressure scenario 4
Pressure [Pa]
42500
37500
32500
27500
22500
17500
12500
7500
2500
-2500
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
2160
2340
2520
2700
2880
3060
3240
3420
3600
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30

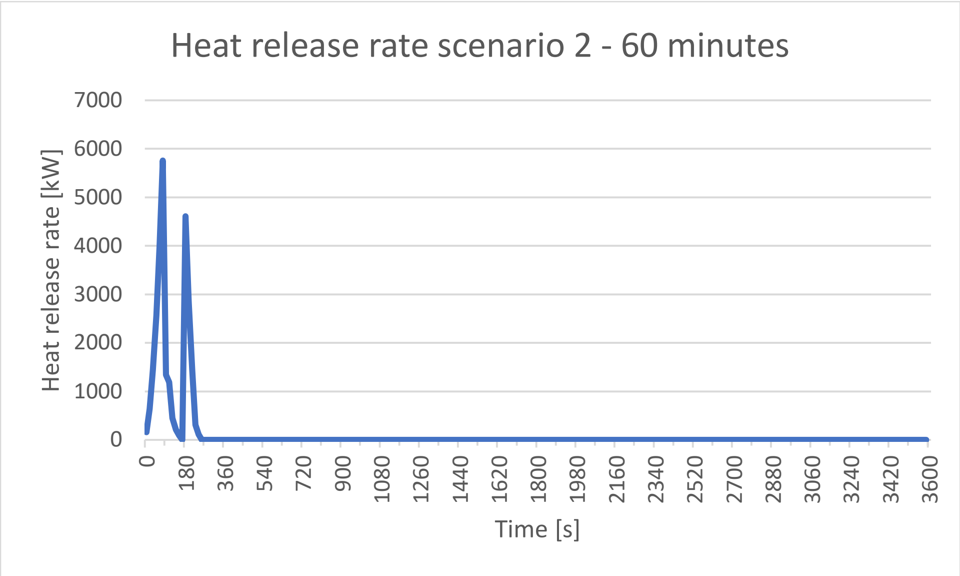

Pressure scenario 4
Pressure [Pa]
19000
14000
9000
4000
-1000
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360
Time [s]
comp 2
comp 3
comp 4
comp 8
comp 13
comp 30

6. Heat release rate additional simulations

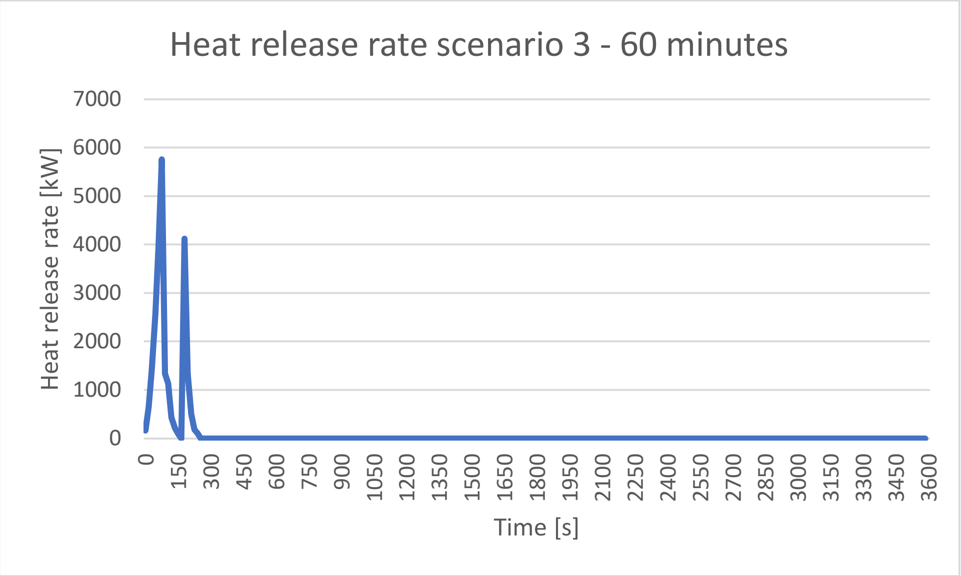
Scenario 1 – 60 minutes



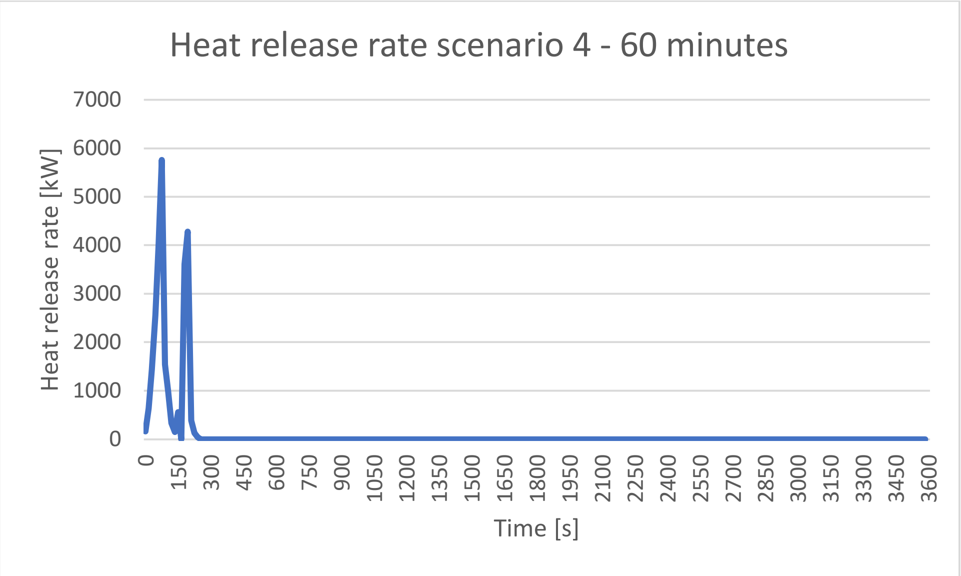
Scenario 2 - 60 minutes



Scenario 3 - 60 minutes

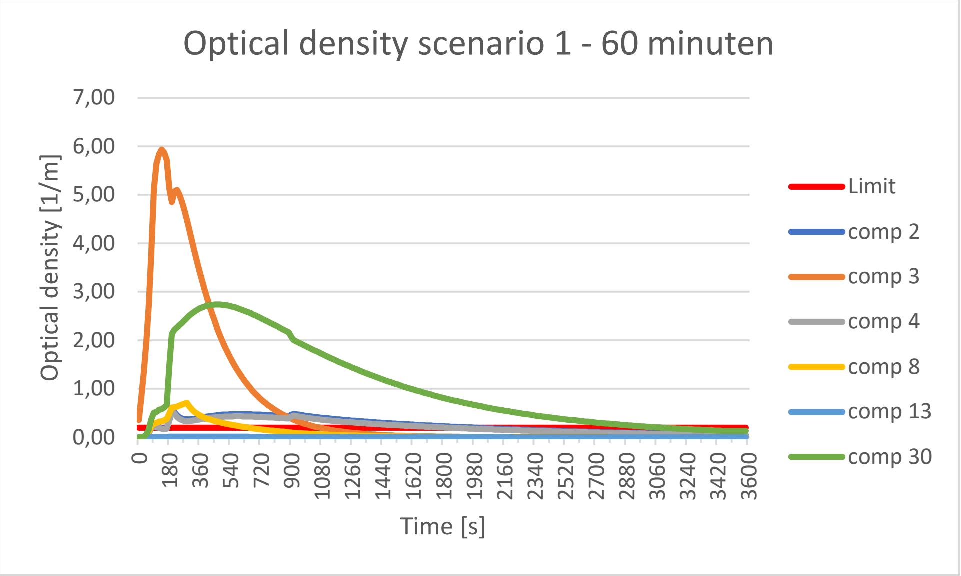


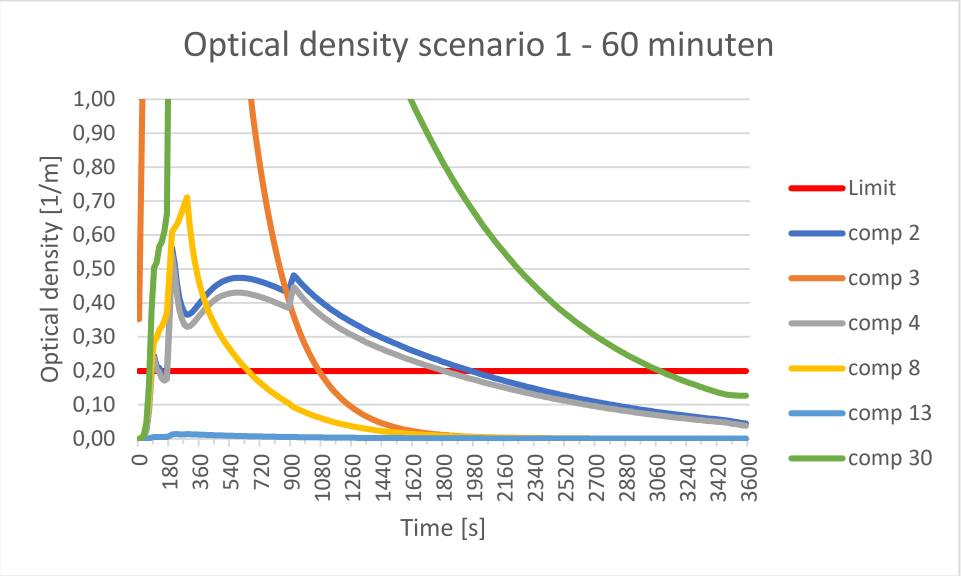
Scenario 4 - 60 minutes



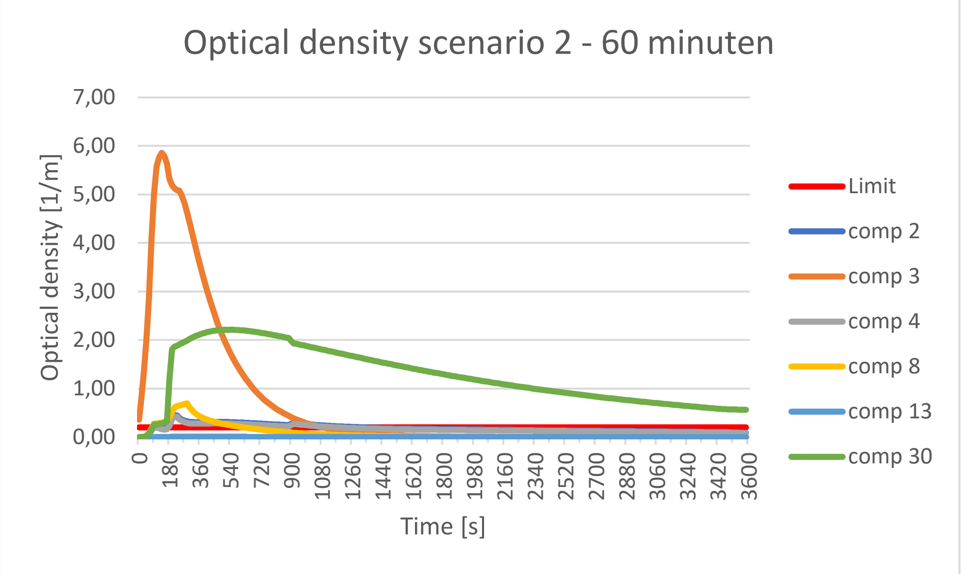
7. Optical density additional simulations

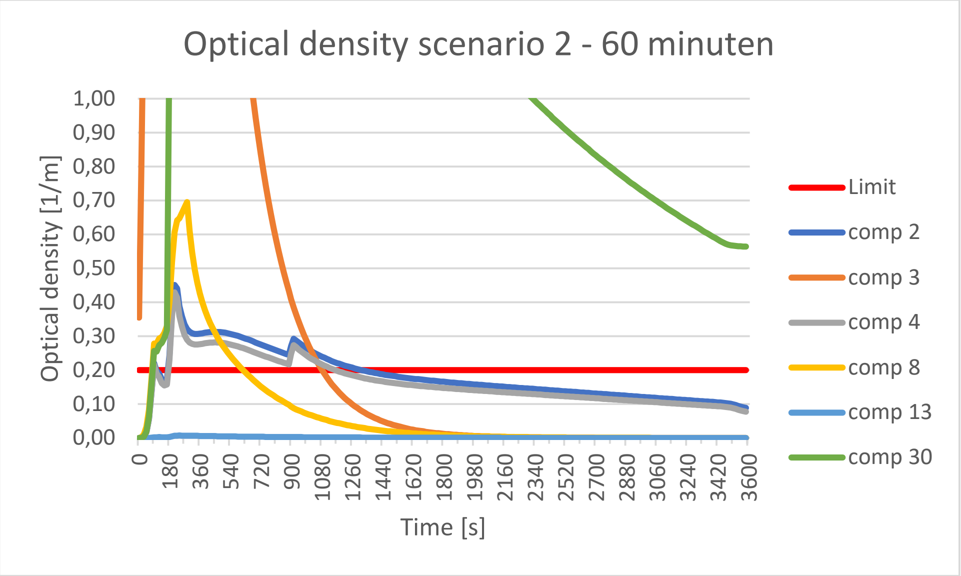
Scenario 1 – 60 minutes



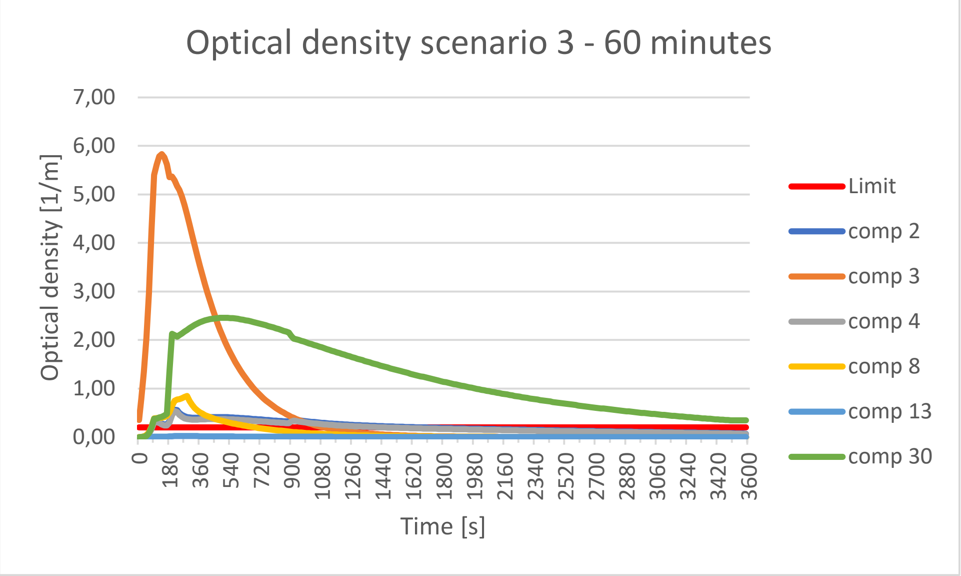


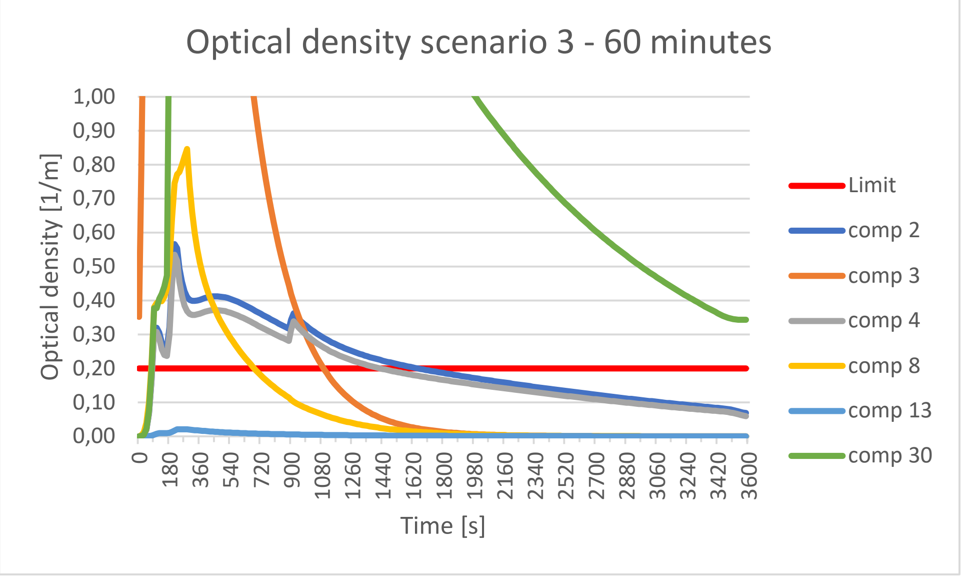
Scenario 2 - 60 minutes





Scenario 3 - 60 minutes





Scenario 4 - 60 minutes