Different concepts for personal safety in a multi-story residential complex in relation to internal smoke propagation

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MASTER THESIS

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Preface

This master thesis is the final product of my graduation project to complete the master program Building Physics and Services at the University of Technology in Eindhoven. The research towards different concepts for personal safety in relation to internal smoke propagation has been done in collaboration with Nieman Raadgevende Ingenieurs and with data from the Instituut Fysiek Veiligheid (IFV) experiments in Oudewater, The Netherlands.

The research started after speaking to Ruud van Herpen about the stay-in-place principle. He mentioned the unique opportunity to base the research on the full-scale experiments conducted by the Instituut Fysiek Veiligheid. Data and insights from these full-scale experiments could then support my research.

I want to thank Ruud van Herpen for his support throughout the research and the opportunity to do this in collaboration with Nieman Raadgevende Ingenieurs. Within Nieman, I was supported by Claudia Rojas in making various computational models and by answering any questions I asked her. I would also like to thank the IFV for making data and insights available from the unique experiment conducted in Oudewater. I also want to thank Prof. Wim Zeiler of the Eindhoven University of Technology for his feedback and guiding my research.

Finally, to everyone that supported and helped me during this research, family, friends, and (old)fellow students thank you!

Enjoy reading,

Marc Scholman

Utrecht, 22 October 2020

Summary

Smoke is the biggest problem in a fire, especially in the so-called senior complexes where people continue to live independently until a later age. It is harder for those people to escape because they are less vital. Also, modern inventory ensures more and more smoke development during fires through the use of synthetic materials. That combination, more and more smoke, and difficult escape turns out to be deadly. This research investigated the possibility of using a stay-in-place concept in a multi-story residential complex. With a literature study, an investigation into the smoke spread and stay-in-place concepts is performed. Hereafter, the experiments and simulations performed.

A case study has been carried out based on an improved model to comply with the current regulations of the Dutch Building Code. Full-scale experiments performed in a former senior residential complex in Oudewater, The Netherlands forms the base of this research. In the case study, various measures are simulated to determine the effect on the optical density and temperature in the adjacent apartments and the corridor. With these results, it can be determined to what extent the various measures contribute to the realization of a stay-in-place concept.
This research uses multizone software models CFAST and B-RISK. To determine whether these models are suitable for simulating a fire scenario, a validation study was carried out. It is based on the full-scale experiments for which data has been made available. The available dataset consists of the measured temperatures and oxygen concentrations in the apartment of fire origin and corridor. In addition, the weight reduction of the fire object (sofa) is known. The validation study shows that CFAST shows better similarities in this case than B-RISK.

The results of the case study show that by applying a combination of measures, the conditions in adjacent apartments can be improved compared to the baseline situation. The spatial conditions in the adjacent apartments meet the set optical density limit of 0.1 1/m. In the corridor, an optical density limit of 0.2 1/m has been used. Temperature does not appear to be a problem in any of the simulations to meet the set limits. The combination of an improved airtightness, a sprinkler system, and a different type of fuel appears to be the most effective. As a result of the different combination of measures, available safe egress time can be extended by 29%.

In conclusion, applying a combination of measures can enable the application of a stay-in-place concept. Smoke propagation can be reduced by first changing the type of fuel to cellulose materials, secondly improving the internal airtightness and adding a sprinkler system. However, the used assessment criteria are not reliable enough, and future research is necessary to confirm the possibility of applying a stay-in-place concept in a multi-story residential complex.

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1 Introduction

1.1 Problem definition

"Nowadays, smoke distribution is the biggest problem during a fire in buildings. However, we still do not know enough how the smoke is spreading and how this can be limited," says professor Fire Prevention René Hagen [3].
The combination of an ageing population that lives longer, and independently living up to a later age makes it important to consider the current regulations. Current guidelines of the Dutch building code for escaping during a fire does not suit the target group who live in residential complexes. The compartmentalization of buildings also does not satisfy the prevention of smoke spread, while this is the greatest threat to residents. A possible concept to help this is the stay-in-place concept that can protect the elderly people that live in residential complexes.

The problem definition consists of two aspects: the ageing of the population of the Netherlands and the energy transition. In the Netherlands, the population is aging and is expected to continue to age in the coming years (Figure 1-1) [4]. Additionally, elderly people also continue to live on their own until an increasingly higher age than before [1]. The type of buildings they live in are often residential complexes with separate apartments, shared facilities and care delivered to their apartments. These residential complexes are considered buildings with a standard residential function by the Dutch Building Code (BB 2012). For the residential function, except for the 24-hour care residential function, an internal emergency response organization is not required. The Building Code assumes that the residents save themselves in case of a fire, but for elderly residents, this is certainly not the case in practice since they are not always self-reliant [1]. Secondly, as a result of the current energy transition, buildings are built more airtight and are better insulated. The presumption is that the energy transition will increase the chances of fire arising and the increase of internal smoke propagation.

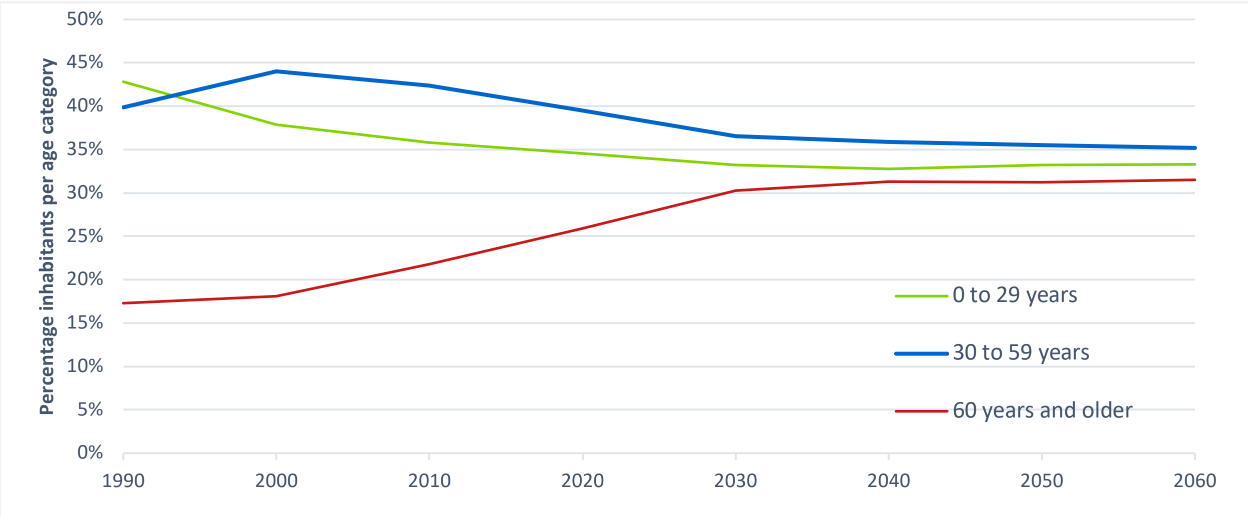


Figure 1-1 Percentage of inhabitants in the Netherlands per age category per year [4].

A study conducted by the Instituut Fisieke Veiligheid (IFV; Institute for Physical Safety) investigated 77 fire incidents and concluded that self-rescuing in the event of a fire in a residential complex is a big concern. Based on data of 50 cases, the study showed that in 88% of these cases, the residents did not rescue themselves [5]. For these residents, smoke is the most significant danger to their chance of survival. Smoke inhalation is more life-threatening for the elderly than for people younger than 65. Moreover, the elderly are less mobile during a fire, and this can be a fatal combination. Research by the Fire Service Academy has shown that due to fires more than 2.5 times as many deaths occur among people over 65 as among people younger than 65 [1]. Current guidelines of the Building Code for evacuating during a fire do not suit the target group who live in these residential complexes "In a sense, smoke and smoke propagation are many times more dangerous than fire," says De Witte [6]. "Smoke spreads much faster and more unpredictably than fire, which means that people can unexpectedly end up in a dangerous situation."

How threatening the conditions during a fire are, mainly depends on temperature, optical density, toxicity, and the irritant effect of the smoke gasses [35]. In order to escape safely, enough time to escape is needed before the conditions inside the building become threatening. Therefore, the Available Safe Egress Time (ASET) must exceed the Required Safe Egress Time (RSET). The difference between the two is the safety margin (Figure 1-2)[2]. The conditions inside the building determine ASET, and the speed of evacuation determines RSET. In senior residential complexes, the RSET will be very long.

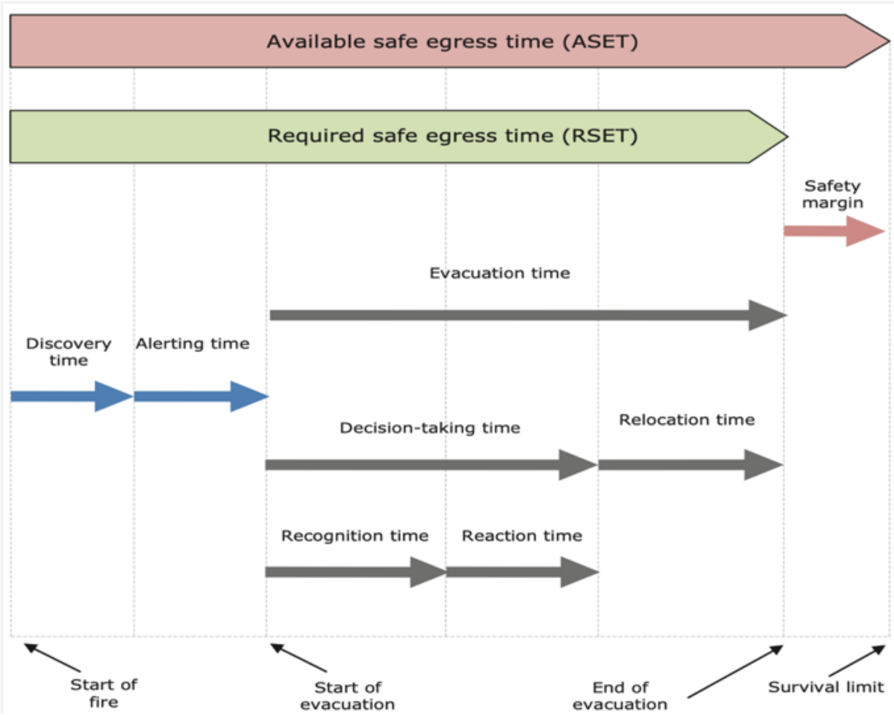


Figure 1-2 Timeline for evacuation [2].

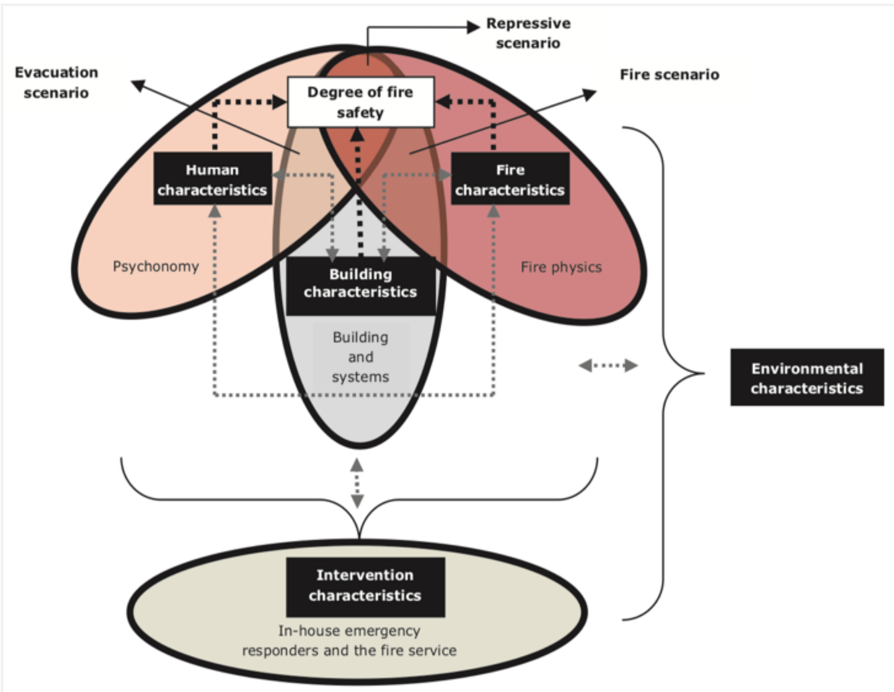


Figure 1-3 The degree of fire safety [2].

According to the IFV, fire safety in the built environment depends on many factors and can be approached from five interrelated disciplines [2]: Human, Building, Fire, Intervention, and Environmental characteristics. Together they determine the degree of fire safety (Figure 1-3). Each discipline has an influence on the behavior of a fire. By changing a discipline, it is possible to prevent internal smoke propagation.

In the Netherlands, there currently is a debate about the stay-in-place principle during residential fires in complexes, due to the ageing population and the lack of self-rescuing capacity of the residents. Some believe that the best approach in case of a fire is to apply the stay-in-place principle [7]. A stay-in-place concept is a non-evacuation strategy where, during a residential fire, it is not intended to evacuate the entire residential complex. Only the residents of the apartment where the fire is originated need to escape initially, while other residents may remain in their apartment [12]. With a stay-in-place concept, the ASET must be larger than the burning time + safety margin. The ASET is measured in the adjacent apartment and not in the corridor (the escape route) because residents should stay in their apartments except for the apartment of fire origin. For these elderly residents, a stay-in-place concept could lead to a considerably higher safety level compared to the evacuation strategy of the BB 2012 [11].

In the Netherlands, the stay-in-place concept has not been accepted or included in the BB 2012 yet (Appendix 1). In England there are residential buildings and flats built according to the stay-in-place concept, also called stay put. In England in the period 2009-2010, there were over 8,000 fires in these kinds of buildings. In only 22 fires necessitated the evacuation of more than five people with the assistance of the fire and rescue service [12]. In 2017 and 2018, 93% of fires in high rise flats resulted in no damage or was damage limited to the compartment of origin [13]. However, when mistakes are made the principle of a stay-in-place can fail, which can be fatal. Therefore, it is necessary to investigate the effect of different measures to understand the possibilities of a different concept for personal safety to protect the elderly people that live in residential complexes.

1.2 Research objective

This graduation project intends to gain insight into the possibility of using a stay-in-place concept in a multi-story residential complex. By investigating different building technical and installation technical measures, this study gains insight into the influence of these different measures on internal smoke propagation. By using multizone simulation models, the spread of smoke in the event of a fire and the ASET per compartment can be determined. It can test whether ASET exceeds burning time and the safety margin can be determined. A significant safety margin is expected to be required because there is no redundant facility in the stay in place concept.

An essential part of the research is validating the simulations with experimental data. The validation will be done by using measurement data from the experiments conducted by IFV/Fire Service Academy in the summer of 2019 in the Schuylenburcht complex in Oudewater [36] (Appendix 2). Two standard multizone models CFAST [25] and B-RISK [26] have been validated based on the experimental data from the IFV.

The gained insight must provide knowledge for building designers and fire safety consultants regarding the stay-in-place concepts. The results of this research will show to what extent a stay-in-place concept can be used and it can potentially contribute to the substantiation to adjust the regulations for these specific type of buildings in the future.

1.3 Research question

It is expected that by using a combination of different building technical and installation technical measures to prevent internal smoke spread, the conditions in adjacent apartments can be kept within limits to survive [36]. Therefore, the following hypothesis is put forward:

"With an approach, based on the current building technical and installation technical possibilities, the application of a stay-in-place concept in a multi-story residential complex is an adequately safe solution".

The hypothesis will be tested by using the research question below. In order to answer this research question, sub-questions are addressed.

Main research question:
- To what extent can a stay-in-place concept be used in a multi-story residential complex in relation to internal smoke propagation?

Sub-question 1:
- What does a stay-in-place concept entail?

Sub-question 2:
- Which building technical and installation technical measures are possible to take in order to extend the available safe egress time?

Sub-question 3:
- Which combination of building technical and installation technical measures contribute to a stay-in-place concept in a new multi-story residential complex?

Sub-question 4:
- Is a multizone software model suitable for simulating smoke propagation and which software model is the most accurate?

1.4 Research relevance

In the Netherlands, fires in senior residential complexes resulting in the evacuation of the entire complex, occur regularly. During an 18-month period, 77 fires in senior complexes happened [5]. An inventory of these fires allows comparing the occurring situation to the hypothetical situation prescribed by the Building Code. Results of the study show that in 18 out of 77 cases, the residents could escape safely within the time which is prescribed by the regulations. This research into the theory of regulations and the practice of fires in senior housing complexes confirms what on earlier studies into ageing and fire safety already suspected [8, 9, 10].

There is an ageing population with a growing group of seniors who are living together in residential complexes. The evacuation of a senior residential complex requires more effort from firefighters due to elderly people being less self-rescuing compared to younger people [5]. These two reasons make this study towards stay-in-place concepts socially relevant. This graduation project contributes to better understanding and possibilities of stay-in-place concepts.

1.5 Research limitations

This research focused on residential fires in multi-story complexes where elderly people live. It is only focused on a building with a corridor and small apartments. The validation study is based on the performed experiments by the IFV. Not all data of the experiments were made available because the IFV was still doing their research at the same moment of performing this research. The available dataset only consists of temperatures and oxygen concentrations at a certain height. Thereby, the heat release rate of the sofa is an estimation based on the weight loss and heat of combustion of the sofa. Within the case study, there is an air leakage through the internal partition construction towards the corridor and the external partition construction to the outside. The leakages to adjacent apartments are not included since they are unknown. However, in practice, due to the high pressure created by a residential fire, smoke spreads through sockets or other seams and cracks, but this is not included in this research.

2 Methodology

In this research, quantitative research is carried out to answer the main research question and thereby confirm or reject the hypothesis. The structure of the research is displayed in Figure 2-1. The first step is the introduction to the problem definition (Section 1). Literature research should provide insight into the relevance of the topic, the research objective, and the formulation of research questions that can fill the research gap. The second step is defining the methodology, including the theoretical framework (Section 2). In this, the theoretical background for answering the research question is explained and framed. The third step is the performed validation study explaining the set-up, results, and discussion. Step four is the case study consisting of the set-up, sensitivity analysis, results, and discussion. Step five consists of a discussion of the results and the methodology (Section 5). Step six is the conclusion and answers are formed based on the research question, which contributes to confirm or reject the hypothesis (Section 6).

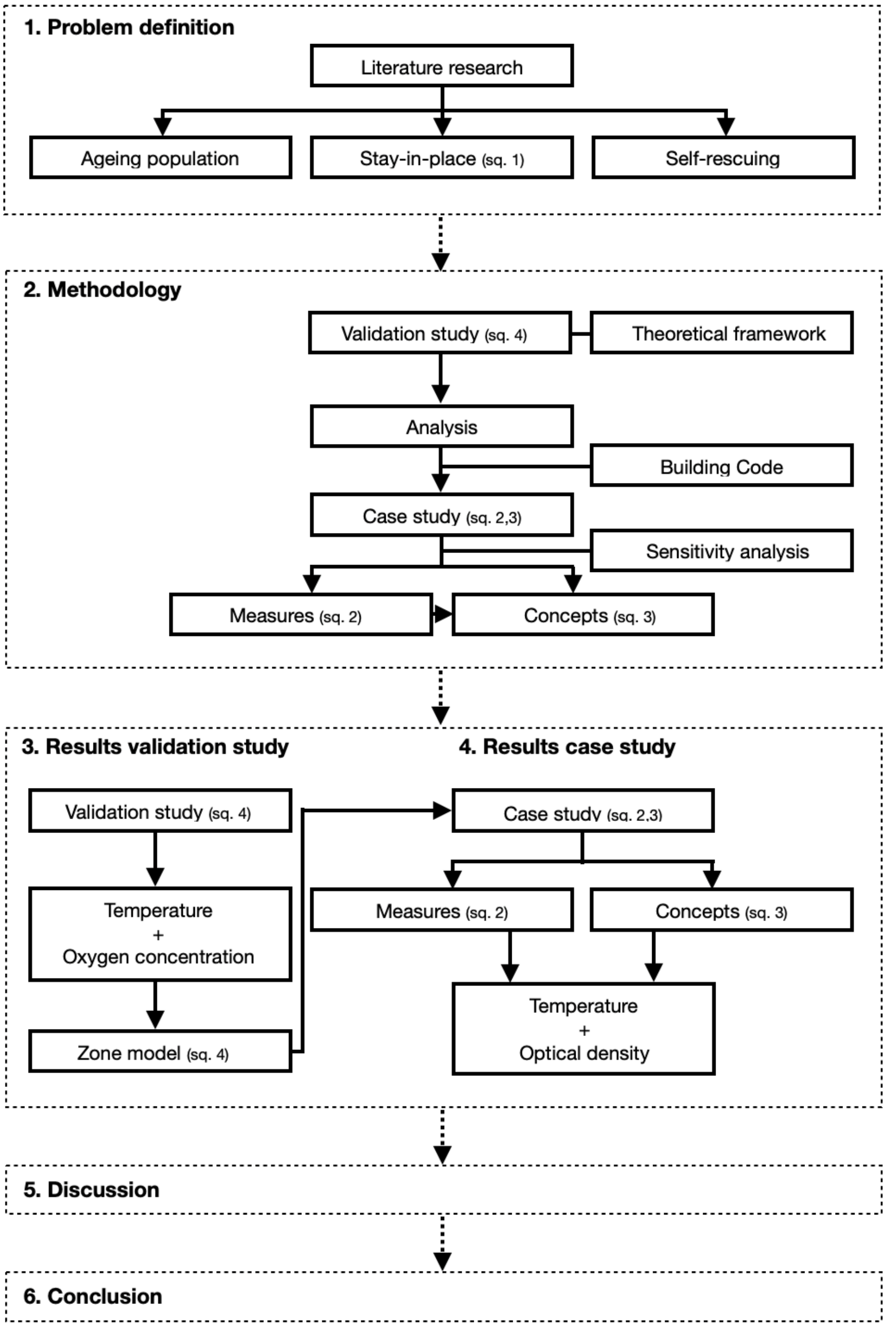


Figure 2-1 Research methodology with the locations for the answers of the sub questions.

Data collection
The literature search is a collection of data from research towards building technical and installation technical measures and the stay-in-place concept. A dataset from the IFV is used for the validation study. Other data for the validation, and case study is collected from simulations of multizone models in B-RISK and CFAST.

Inclusion and exclusion criteria
The literature search only looked into research that addresses the various building technical and installation technical measures in the field of limiting smoke spread within residential buildings in the period 2000 to 2020. The validation study, which is compared with experimental data, is only concerned with the upper layer temperature [°C] and upper layer oxygen concentration [%] in the compartment of fire origin and the corridor. Since at this point, only experimental dataset of these specific compartments and conditions are available.

The case study only examines the upper layer temperature [°C] and optical density in the upper layer [1/m] to determine whether the conditions in a compartment remain within the set limits. Upper layer oxygen concentration [%] is not included because sight length [m] and temperature [°C] in a compartment are indicative of the survivability (Section 2.1.1). The validation study shows that one multizone model generates better results and this model will be used for the case study.

Both studies in this research make use of the experimental set-up of IFV during the experimental measurements. This means that the fire will always take place in the same object at the same position in the apartment. In addition, a closed façade was used, so in this study, doors and windows towards the outside are excluded.

Data analysis
The data collected from the simulations contain much information about different parameters in all compartments. First, the data will be analyzed to determine correctness. Hereafter, the data is cleaned up and analyzed further. Only data from the required compartments and the required parameters will be used. The necessary parameters are:

- Upper layer temperature [°C];
- Oxygen concentration [%];
- The optical density in the upper layer [1/m];
- Actual heat release rate [kW].

Validity and reliability
Internal validity is guaranteed using a validated simulation program. The validation study makes use of experimental data to determine validity. Also, a sensitivity analysis is used to determine which input values influence the outcome of this study the most. The external validity concerns the degree of generalizability of the research. Generalizability can be achieved by examining different cases. In this study, one case is examined, which makes it difficult to generalize the results of this study. However, the simulated residential complex is at Building Code level, and the layout of the complex corresponds to other cases.

The reliability of the validation study depends on the measurements performed by the IFV and the multizone software. It can be assumed that this data made available by the IFV is reliable. The reliability of the case study results is based on the findings during the validation study. The deviation between experimental data and the results from the simulations represents a margin of error to be considered during the case study.

2.1 Theoretical framework

In this section, the theoretical framework of this research is presented. First of all, the stay-in-place principle and smoke production will be discussed. The smoke component and the survival criteria must be defined to answer the first sub-question. Also, the results of the simulations can be put into perspective using this theory. Second, the various building technical and installation technical measures are defined according to the available literature and studies. It will describe what the measure contains and how it can contribute to the stay-in-place concept. These measures will eventually be simulated to form an answer for sub-questions 2 and 3. Third, identifying software is essential. In fire safety engineering, there are several validated software programs available, and two of these are used for a validation study in order to answer sub-question 4.

2.1.1 Stay-in-place concept (sub-question 1)

In this research, it is assumed that a stay-in-place principle is a non-evacuation strategy. This means that during a residential fire, no evacuation of the entire residential complex takes place. Only the residents of the apartment where the fire is originated initially need to escape. In BB 2012, the rules regarding fire safety have been set up differently. The aim is to ensure that residents should be able to escape safely (Appendix 1). It is assumed that residents can travel a short distance where smoke is present as a result of smoke propagation.

Research shows that during a fire in this type of building, smoke spread causes the most significant danger (IFV). This is because smoke can propagate quickly through a building. The smoke spread is the result of pressure differences between compartments. These pressure differences can arise in the usual situation, as a result of temperature difference between inside and outside, wind attack on the building, and due to the ventilation system. In the event of a fire, a pressure difference will be generated as a result of thermal expansion or smoke gases [37].

Smoke consists of various toxic substances (Appendix 3). The composition of smoke is determined by various factors such as the fuel itself, but also the spatial conditions. When there is too little oxygen in the compartment for combustion, incomplete combustion (underventilated situation) of the fuel will take place. Figure 2-2 shows that the production of carbon monoxide (CO) and soot depends on the amount of oxygen available for combustion. Yields will be constant for a given fuel as long as $\Phi < 1$ (overventilated situation). Incomplete combustion ($\Phi > 1$) produces more smoke and thus more CO and soot.

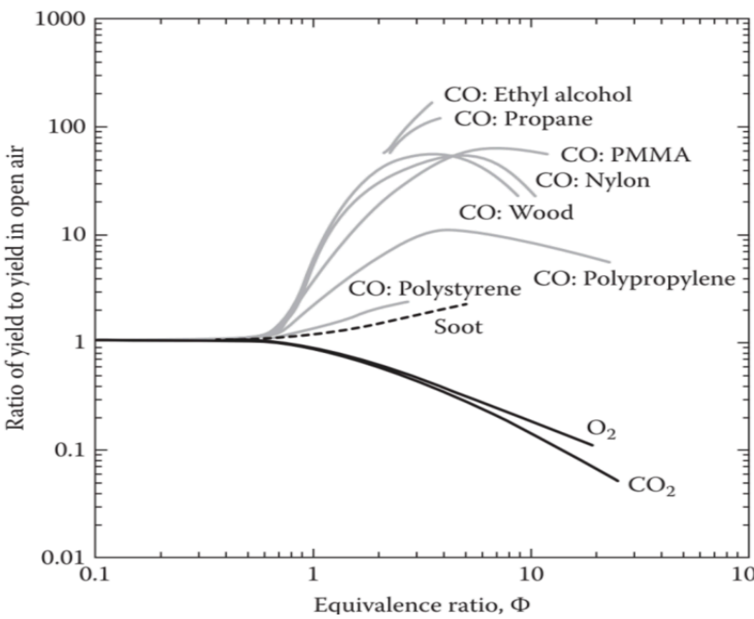


Figure 2-2 Effect of underventilation on yields production [38].

When applying a stay-in-place concept, it is essential to prevent internal smoke spread during a fire as much as possible. Nevertheless, smoke propagation is not completely inevitable, and a threshold value is used to limit the health damage of building users (Swedish Building Code, European Guideline 19 and ISO 13571) [30]. The maximum permissible values depend on the situation that arises, a stratified or mixed situation.

In the corridor where a stratified situation will occur, there will be two zones. The hot smoke layer must remain at the height of at least 2.5 meters in the escape route. The temperature of the smoke buffer does not exceed 200 °C [30]. Also, the CO-dose must be lower than 35,000 ppm/min and O_2 concentration higher than 60,000 ppm, but with sight lengths of more than 5 meters, the toxicity of the smoke is not significant [30]. In a stay-in-place concept, only residents of the apartment where there is a fire need to escape safely. Nevertheless, a safe escape route can be a redundant facility to improve the stay-in-place concept.
In the adjacent apartment a mixed situation will occur, there is only 1 zone. The conditions in this zone must comply with a maximum gas temperature of 70 °C and a sight length of at least 5 meters. Although the human factor is not included in this study, a more severe limit is desirable. It is expected that residents try to escape when they can no longer orientate in their apartment. In this research an extra safety margin is built in, the limit is increased to a minimum of 10 meters sight length in the adjacent apartments.

2.1.2 Building and installation technical measures (sub-question 2 and 3)

The principle of Building technical, Installation technical, and Organizational (BIO) measures is an integral fire safety approach with the interplay and correct application of various fire protection measures [33]. The measures provisions that prevent the start and spread of fire and smoke. This research is only focused on the building technical and installation technical measures. A literature study was performed to investigate the possible measures to prevent the spread of smoke. The number of studies carried out concerning internal smoke propagation and associated measures is limited. Below an overview of measures which affect smoke propagation that are being simulated in this research:

Sprinkler system
This fire repression installation must ensure that the fire is limited to a compartment and does not fully develop. A study performed at Nieman [30] shows that applying sprinklers is a measure that slows the deterioration of conditions in a residential building which benefits personal safety. Also, adding sprinklers to a residential building reduces the risk of damage when a fire develops [18].

Ventilation system
A mechanical ventilation system must meet the requirements set in the Building Code and therefore, also prevent the spread of smoke. When a fire starts, the temperature will rise, and valves in the ducts will close to prevent smoke from spreading. The ventilation system can play a role in preventing smoke from entering other apartments. In other apartments, connected to the same corridor as the apartment of fire origin, the air supply must not switch off. Overpressure must be created in the other apartments instead of under pressure. Under pressure ensures that smoke and gases are sucked in the apartment [34].

Airtightness
In the event of a fire, the pressure is built up in the apartment of fire origin. Ultimately, this results in the spread of smoke through cracks and seams because smoke is pushed out of an apartment into areas where the ambient pressure is less high. By improving the airtightness towards internal compartments, it will theoretically work in such a way that smoke searches for the path of least resistance and goes to the outside. However, it is not obvious to make this internal construction better airtight than the façade. The expectation is that with an increasingly stricter requirement, the façade should mainly be improved.

Pressure valve
A pressure valve in the façade can lower the pressure during a fire scenario. Pressure difference inside the apartment above 50 Pascal [EN 12101-6] compared to the outside, results in a difficult to open front door [23]. By implementing a pressure valve, the pressure can keep below 50 Pascal for a more extended period. Also, smoke propagation towards a corridor can be minimized. A valve can be installed in the façade or connected to the ducts of the ventilation system. First, research is needed towards the resistance of a ventilation system and the opportunity to use this system as a pressure valve.

Type of fuel
Research has been carried out into the production of smoke in domestic fires [35]. Nowadays, an inventory consists of synthetic materials in more and more dwellings, whereas in the past they had more cellulose materials. The difference in a fire is noticeable in the production of smoke. Synthetic materials produce considerably more smoke than cellulose materials. In theory, the use of cellulosic materials should reduce production of smoke resulting in a lower optical density.

2.1.3 Multizone software models (sub-question 4)

In the field of fire safety engineering, numerical models are often used to predict the behaviour of fire and smoke spread. These numerical models can roughly be divided into two categories: zone and Computational Fluid Dynamics (CFD) models. CFD models are mainly used for issues where it is essential how heat and smoke dispersion are in one single compartment. CFD works with a domain which is divided into small cells. A zone model, on the other hand, is more suitable for issues in which several compartments play a role. Two-zone models are mostly used to estimate the conditions during a pre-flashover fire where the separation of an upper layer from a lower layer allows the estimation of species concentration [19].

The validation within this study consists of a comparison between two different multizone models, CFAST and B-RISK. CFAST is an international validated calculation model for fire scenario development and smoke propagation in buildings [24]. The model can be used to determine the survival chances of users, and the effects of various fire prevention measures can be investigated. According to Jones et al., Appendix D [28]: "CFAST is a widely used model of fire growth and smoke transport". Results obtained from CFAST simulation show good agreement with experimental measurements, although in some cases, there is an over-prediction of the upper layer temperature [28]. B-RISK fire risk modelling software is relatively new and developed by BRANZ and the University of Canterbury based on New Zealand regulations [26]. It is a quantitative risk analysis tool that incorporates risk-informed functionality. It makes use of a combination of deterministic and probabilistic calculation functionality. The stochastic Monte-Carlo simulation is included to deal with the risk and uncertainty [27]. According to benchmarking examples [29] of B-RISK between experimental data and model predictions, it is possible to see the level of agreement. This report does not draw detailed conclusions, but there is shown a good agreement between experimental and numerical data [29].

The difference between B-RISK (version 2019.03) and CFAST (version 7.4.2):

- In B-RISK it is possible to specify a probability distribution of stochastic boundary conditions so that a sensitivity analysis is not necessary. CFAST can only calculate with fixed values, so a sensitivity analysis is required for stochastic boundary conditions.
- In CFAST, the lower oxygen limit (LOL) can be specified. In B-RISK it is not possible to specify the LOL. The minimum oxygen concentration needed for combustion to occur is in this program assumed to vary between 2% and 10% depending on the gas temperature [26].
- In CFAST, plume mass entertainment is estimated by using Heskestad's correlation [25] [31]. In B-RISK the entertainment of the plume in the far field is based on Heskestad's correlation and at lower heights, where the plume model is not valid, the McCaffrey correlations are used [26].

3 Validation study

The validation study consists of a comparison of data from experiments and computational models. In this section, the computational model with the associated input parameters will be discussed. The goal is to identify and visualize the fire scenario, which can be expected during a fire in a building with corridors, based on the experimental set-up. By performing a comparison, it can be concluded whether computational models can be used for fire safety engineering. A distinction is made between two different models CFAST and B-RISK. The IFV has carried out the experimental approach. For information about the experimental set-up and performed experiments in the Schuylenburcht complex in Oudewater, visit www.ifv.nl.

The available dataset of the experiments consists of the temperature and oxygen levels in the apartment of fire origin and the corridor during the IFV experiment (Figure 3-1). The output is obtained from both the apartment (1.19) and the corridor (1.29). The fire is originated in the apartment, and the corridor will be used to escape the building (Appendix 2). The oxygen concentration is measured at a height of 1.5 meters. The temperature is measured in the apartment and corridor at 2.2 meters, where the corridor has measurement equipment in two places. In this research, the average of these two values is used.

Experimental baseline measurement (IFV):

- Upper layer temperature [°C];
- Upper layer oxygen concentration [%].

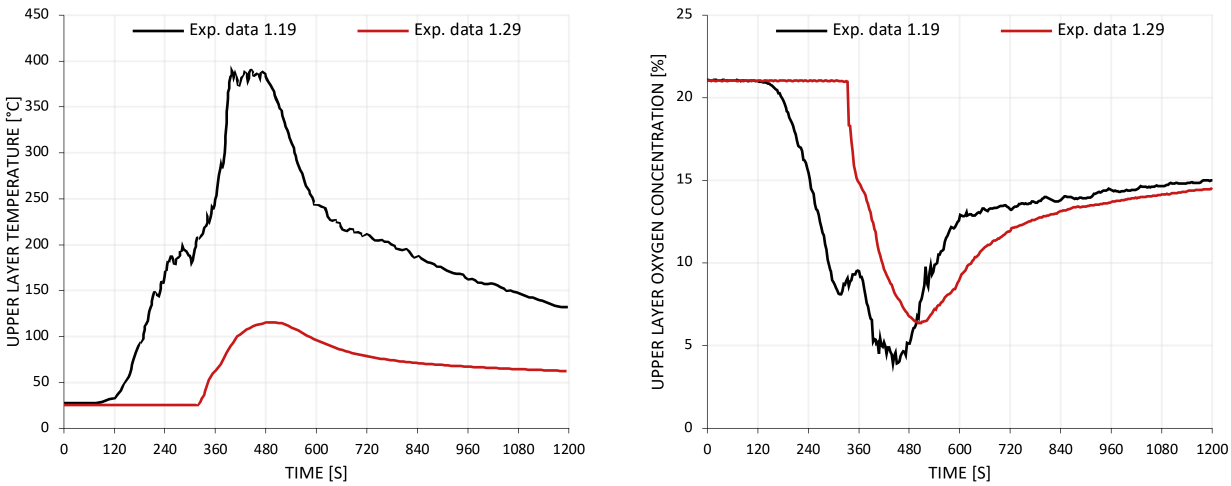


Figure 3-1 Measured temperature (left) and oxygen concentrations (right) in apartment 1.19 and corridor 1.29.

3.1 Set-up

3.1.1 Computational model

Geometry

In Figure 3-2, the floorplan of the Schuylenburcht complex in Oudewater is depicted. The overlaying geometry for the simulations is a simplified version. Simplification of the geometry resulted in a lower need for computational power for the simulations. The geometry consists of two apartments positioned opposite of each other, separated by a corridor. An apartment is divided into two areas that are openly connected to each other, the living room where people sleep and the kitchen. The bathroom was not included in the model because tests were carried out with a closed door during the experiment. Appendix 5 shows the input parameters of the geometry for the simulations.

Figure 3-2 Floorplan first floor Schuylenburcht complex.

Materials

In both multizone models B-RISK and CFAST, it is necessary to define materials to the different partition structures. There is only a difference made between the floor, ceiling, and walls. The façade and separation walls are therefore made of the same material. The walls exist of bricks and floors and ceiling are concrete (Table 3-1). The materials per partition structure are the same for all compartments.

Table 3-1 Material properties.

Partition	Material	Thermal Conductivity [W/mK]	Thickness [mm]	Density [kg/m³]	Specific heat [J/kgK]	Emissivity [-]
Wall	Brick	0.69	200	1600	840	0.90
Floor	Concrete	1.2	200	2300	880	0.94
Ceiling	Concrete	1.2	200	2300	880	0.94

Airtightness

Nieman Raadgevende Ingenieurs performed multiple airtightness measurement in the Schuylenburcht building in Oudewater. In total, three apartments were measured according to NEN2686/NEN-EN-ISO 9972. The results of the measurements are shown in appendix 4, including the description of the measurement set-up. The results of the measurements show a widespread of airtightness per apartment. When looking at the apartments objectively, it can be seen that in apartment 1.19 and 1.20 openings are present in the partition construction. These provide extra air leakage which does not correspond to the experiments. These additional air leaks were closed during the experiments in apartment 1.19. It is assumed that the airtightness of apartment 1.21 is, therefore, representative for all apartments. Table 3-2 shows the results of the measurements in apartment 1.21.

Table 3-2 Results airtightness measurements apartment 1.21 according NEN 2682, performed by Nieman.

Apartment 1.21	Total	Internal	External
qv;10 [dm³/s]	96	81	17
Leakage area [cm²]	150	116	34

No airtightness measurements were carried out in the corridor. As a result, an assumption has been made for the airtightness of this compartment. Based on a visual survey, it has been established that the two double doors in the corridor are not properly airtight. A width of 0.2 cm is assigned to the total length of the cracks present in the double door in the corridor. This results in an equivalent surface area of 208 cm^2.

Vents

The total equivalent surface area of openings per apartment is based on the performed airtight measurements (Table 3-2). By creating a small opening in the compartment, the air leakage is included in the model. This opening must be applied over the entire height of the compartment in order to affect the fire behavior within the apartment as little as possible, resulting in:

Apartment towards corridor: 116 cm^2 → 0.45 cm width and 260 cm height
Apartment towards outside: 34 cm^2 → 0.13 cm width and 260 cm height

During the baseline measurements, there were doors opened and closed. Therefore, the doors are included in the computational models (Table 3-3). The door of apartment 1.19 towards corridor 1.29 is opened and closed on an exact same moment in each experiment. The door of corridor 1.29, towards the staircase, is opened and closed hereafter. This is due to the firefighter igniting the fire object and leaving the corridor. The moment of opening and closing this door is an assumption. In Figure 3-3, a 3D-views of the computational model can be seen, both CFAST and B-RISK are similar; the pink lines represent the openings.

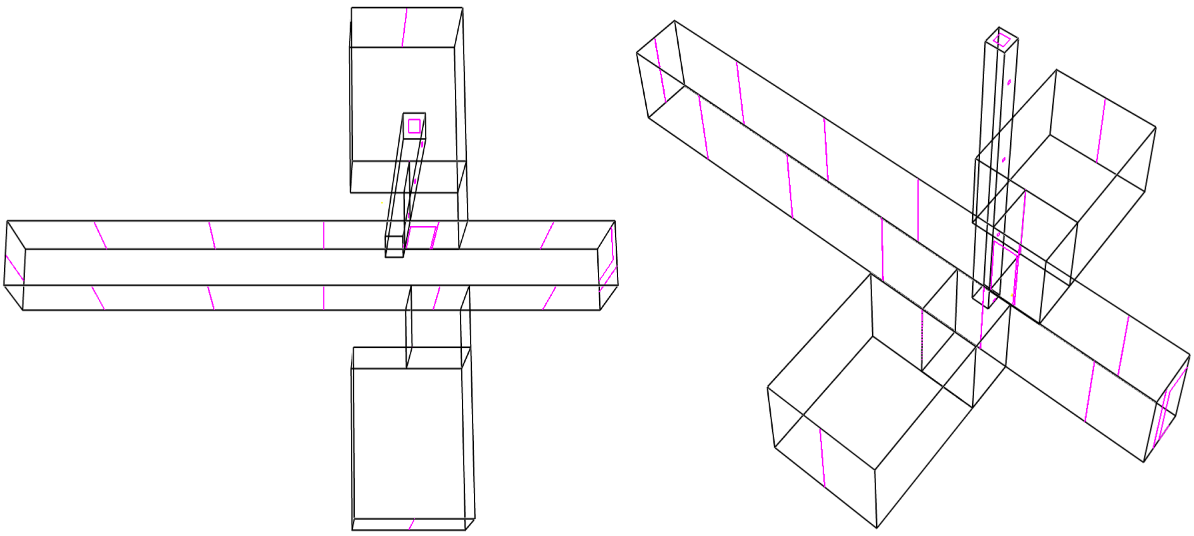


Figure 3-3 Isometries (wire model in 3D) of the simulated situation in Smokeview.

Table 3-3 Overview doors computational model.

From compartment	Towards compartment	Width [cm]	Height [cm]	Opening [s]	Closing [s]
1.19 Kitchen	1.29 Corridor	80	210	300	0
1.29 Corridor	Outside (imaginary staircase)	90	210	320	330
1.19 Living room 1.26 Living room	1.19 Kitchen 1.26 Kitchen	180	260	0	0

Fire object

The experiment performed by the IFV makes use of only one fire object inside the apartment, which is a 2-seater sofa (Figure 3-4) [32]. The dimensions of the fire object are 0.97x2.03x0.82 meters. The sofa is made of different materials, the combined molecular formula of combustion materials is $CH_{1.63}O_{0.558}N_{0.028}$ [35]. Based on the findings after the performed experiments, the fuel input required some changes. The findings were as follows: the sofa itself hardly burns within the short time of the experiments, only the foam inside the sofa burned. Therefore, the molecular formula mentioned above does not apply, and a molecular formula of foam ($C_9H_{16}O_3N_{1.4}$) with a heat of combustion of 21.8 MJ/kg must be used for the simulations [35]. The HRR curve can be derived from the weight loss measurements of the experiments in Oudewater (Figure 3-4).

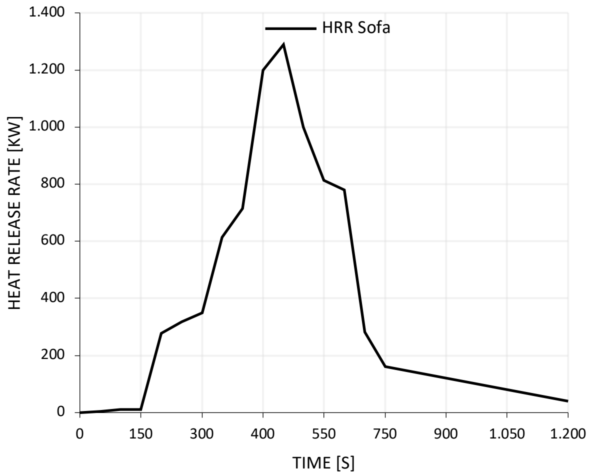


Figure 3-4 Experimental set-up inside apartment 1.19 with the 2-seater sofa (left) and the HRR curve of the 2-seater sofa (right).

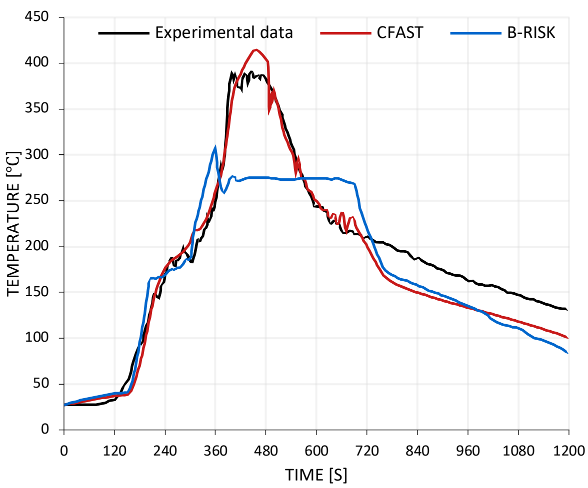
3.2 Results

The validation study is based on a comparison between the results and available data of the experiments in Oudewater. It is modelled in CFAST and B-RISK with a comparable set-up. The boundary conditions, airtightness, and HRR are deduced from the experiments. The results of the simulations are presented in graphs for visual comparison with the experimental data (Figures 3-5 and 3-6).

Upper layer temperature

In Figure 3-5, the upper layer temperature of both experiment and simulations are shown. The measured and predicted temperatures in the apartment of fire origin show good agreement for CFAST. However, there is an overprediction of 30 °C during the temperature peak in CFAST. B-RISK results matches for the first 360 seconds. Hereafter, the fire becomes oxygen controlled, and the temperature in the apartment is at a constant level of 275 °C for 300 seconds.

In the corridor, both models show an underprediction of the peak temperature. CFAST shows an underprediction of 5 °C and B-RISK 30 °C since in B-RISK the fire is oxygen controlled after 360 seconds. This also affects the temperature curve in the corridor. For the same period as in the apartment, a constant temperature is reached in the corridor.



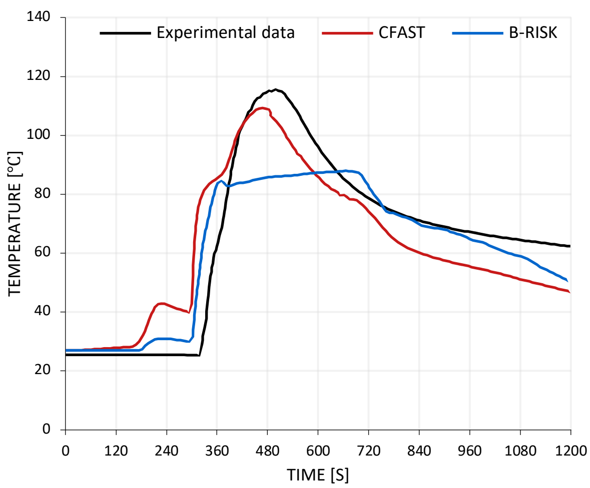


Figure 3-5 Upper layer temperature in apartment 1.19 (left) and upper layer temperature in corridor 1.29 (right).

The results are summarized in Table 3-4. It can be noticed that the time to peak in CFAST shows similarities with the experimental data. There is a 40-second delay in the apartment, but this is due to the overprediction of the temperature. In the corridor, time to peak is almost similar. More considerable differences have been noticed in the results of B-RISK. Nevertheless, both models react similarly when the front door of the apartment is opened.

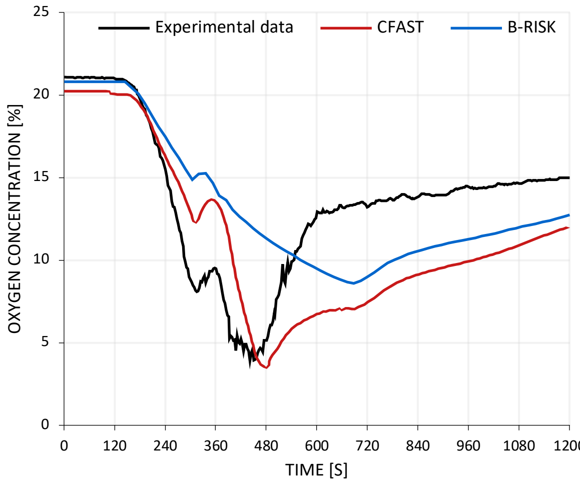
Table 3-4 Comparison between experimental data and computation model predictions of the upper layer temperature [°C] based on [28].

Compartment	Data obtained from	Peak value [°C]	Time to peak [s]	Similar as experiment
Apartment 1.19	Experimental data	380	410	-
	CFAST	410	450	Yes
	B-RISK	300	360	Yes
Corridor 1.29	Experimental data	115	480	-
	CFAST	110	480	Yes
	B-RISK	85	360	No

Oxygen concentration

In Figure 3-6, the oxygen concentration of both experiment and simulations are shown. The measured and predicted oxygen concentration in the apartment of fire origin does not always show good agreement for CFAST and B-RISK. In the apartment, the oxygen concentration from experimental data drops towards 8%, then a small increase due to opening the door and hereafter another drop towards 4%. In CFAST, and more or less in B-RISK, this is also shown but with higher oxygen concentrations. The drop in CFAST is as low as measured in the experiments.

In the corridor, the results from CFAST are in line with the experimental data up to and including the drop. The drop-down and oxygen concentration levels are similar. B-RISK shows no agreement except for the first 300 seconds of the experiment. The main difference between the computational models and experimental data is the build-up phase of the oxygen concentration after the drop in the apartment and corridor. During the experiment, the oxygen concentration will recover quicker to the initial value compared to the results of both models.



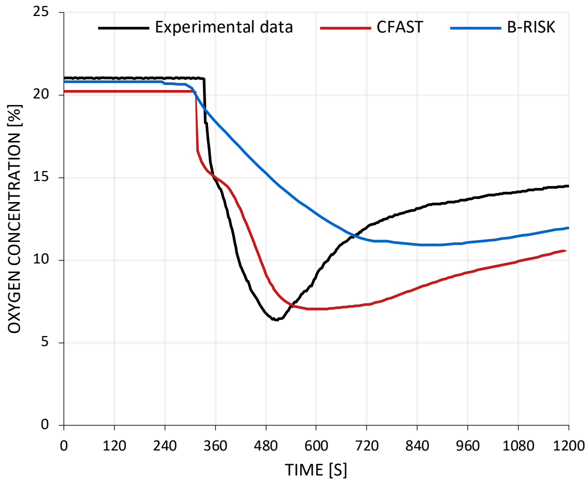


Figure 3-6 Upper layer oxygen concentration in apartment 1.19 (left) and upper layer oxygen concentration in corridor 1.29 (right).

The results are summarized in Table 3-5. It can be noticed that the results from CFAST achieve almost the same trough value as the experiment. In the apartment, there is an overprediction of 0.5 % and a delay of 30 seconds. In the corridor, there is an underprediction of 1.0% oxygen concentration and a delay of 70 seconds. B-RISK shows a much higher oxygen concentration and a trough is not directly visible because the oxygen concentration decreases gradually.

Table 3-5 Comparison between experimental data and computational model predictions of the upper layer oxygen concentration [%] based on [28].

Compartment	Data obtained from	Trough value [%]	Time to trough [s]	Similar as experiment
Apartment 1.19	Experimental data	4.0	450	x
	CFAST	3.5	480	Yes
	B-RISK	8.5	690	No
Corridor 1.29	Experimental data	6.0	510	x
	CFAST	7.0	580	Yes
	B-RISK	11.0	790	No

3.3 Discussion

Validation study

The results of the validation study show that there is a difference between CFAST and B-RISK. The conditions in B-RISK are sooner oxygen controlled than in CFAST. For B-RISK, this results in a lower temperature and higher oxygen concentrations in the apartment and corridor. The difference in the results from the simulation can be explained by comparing the actual heat release rate of CFAST and B-RISK (Figure 3-7). This shows that in B-RISK, the HRR decreases after 360 seconds and has a stable phase of 400 kW. This phase corresponds to the upper layer temperature (Figure 3-5). The results indicate that in B-RISK, the fire is smothered sooner because there is not enough oxygen for combustion (oxygen controlled) in the compartment. The fire simulated in CFAST is also oxygen controlled, but this occurs after 480 seconds. Based on the internal gas energy of the volume in the apartment, CFAST and B-RISK show similarities (Figure 3-7 right). Thus, despite the difference in the temperature of the smoke layer, the energy is more or less the same. The smoke layer in B-RISK is, therefore, thicker than in CFAST. The internal gas energy of the volume can be calculated with equation 2, 3, and 4 [40].

$$E_g = V_g * \rho * c_v(T_g - T_a) \tag{2}$$

$$\rho = \frac{353}{T_g} \tag{3}$$

$$c_v = 0.187 * T_g + 664.95 \tag{4}$$

Where E_g is the internal energy of the gas volume [J], V_g the gas volume [m^3], ρ the density [kg/m^3], c_v the specific heat [J/kgK], T_g the temperature of the gas volume [K], and T_a the ambient temperature [K].

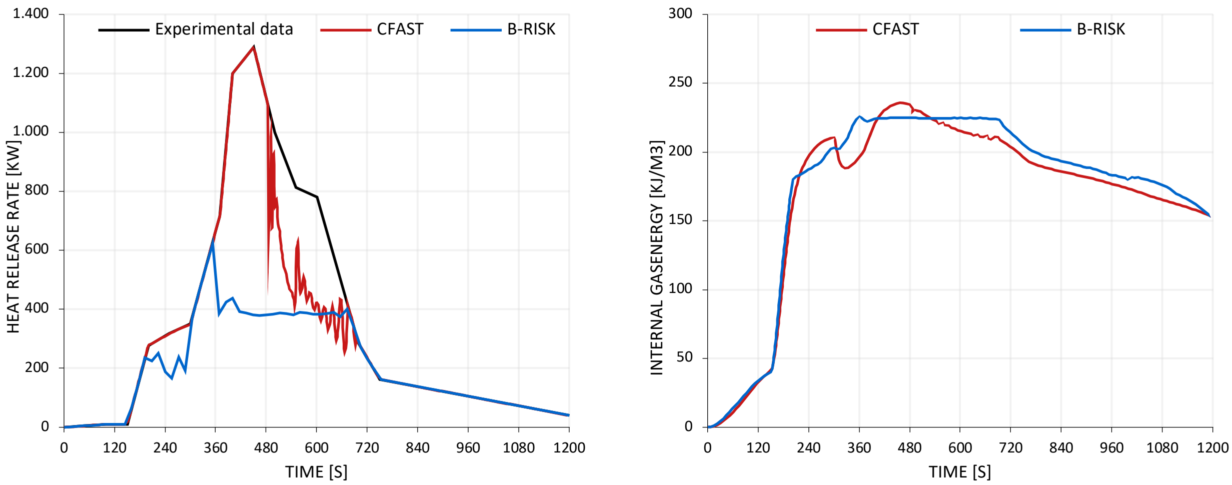


Figure 3-7 Actual heat release rate [kW] during experimental fire test (left) and internal gas energy smoke layer [kJ/m^3] in apartment 1.19 (right).

A possible explanation for the difference between the two programs is the input data for a lower oxygen limit and the use of different plume models. When the results are linked to the available literature, it becomes clear that the results of the validation study show similarities concerning CFAST: an overprediction of temperature. The results obtained with B-RISK do not correspond with the literature (Section 2.1.3). The validation study provides hardly any new insights, but it does show that CFAST can be used in the case study. However, for the case study, it is crucial to know the development of the conditions in the adjacent apartments, and this has not been validated in this study.

4 Case study

The case study consists of two parts in order to answer sub questions 2 and 3. The starting point of the baseline model is the set-up as used for the validation study in the Schuylenburcht complex but with more compartments. Within the new model, the ventilation principle and air leakage are changed, according to BB 2012. The front doors of the apartments are self-closing, according to Bbl 2021. All other input parameters for the baseline model remain the same as described in section 3.1. Appendix 6 contains an overview of all input parameters for the baseline model.

The first part of the case study examines the effect of the different measures on the conditions in the adjacent apartment (1.18) and the corridor (1.29). The results from the first part contributes to formalizing the second part of the case study. Concepts are created and simulated based on these results.

4.1 Set-up

4.1.1 Computational baseline model

Airtightness

The total surface area of openings of the apartment is based on the current regulations (BB 2012 and Bbl 2021). Compared to the airtightness of validation study model, this is an improvement. Each apartment has the same air permeability of 30 dm^3/s. The s200 doors have a maximum air permeability of 5.56 dm^3/s. The equivalent surface area of air leaks can be calculated according to NEN2686 with formula 1.

$$A_e = \frac{C * \sqrt{\rho}}{2^n} \qquad (1)$$

Where A_e is the equivalent surface area [m^2], C is the airtightness coefficient [$dm^3/s\ Pa^n$], ρ is the density of air [kg/m^2], and n the air flow exponent [-]. When applied to the apartments in the Schuylenburcht complex, a total equivalent surface area of 58.4 cm^2 is allowed. In addition, the equivalent surface area of 4 cm^2 of the s200 door is added. Table 4-1 shows the distribution between internal and external air leaks.

Table 4-1 Equivalent surface area apartment 1.19 according BB 2012.

Total: qv;10 dm³/s [Leakage area cm²]	**Intern: qv;10 dm³/s [Leakage area cm²]**	**Extern: qv;10 dm³/s [Leakage area cm²]**
35.55 dm^3/s [62.4 cm^2]	25.55 dm^3/s [39 cm^2]	10 dm^3/s [23.4 cm^2]

Vents

A mechanical ventilation system is included in the model by creating a supply vent in the living room and an exhaust vent in the kitchen. Both vents have a flow rate of 0.019 m^3/s. The corridor also makes use of mechanical ventilation (Figure 4-1). The front door of the apartment is, according to the new regulations, self-closing after escaping the apartment of fire origin. The escape door from the corridor towards the outside is opened and closed later in the simulation (Table 4-2).

The total equivalent surface area of openings per apartment is shown in Table 4-1. By creating small openings over the entire height of the compartment the air leakage is included into the model. This opening must be applied over the entire height of the compartment in order to affect the fire behavior within the apartment as little as possible resulting in:

Apartment towards corridor: 39.0 cm^2 → 0.10 cm width and 260 cm height
Apartment towards outside: 23.4 cm^2 → 0.087 cm width and 260 cm height

In the baseline model a self-closing door is included to meet the current regulations. Opening the door simulates an escaping resident from the apartment where a fire is originated. The opening and closing moment are shown in Table 4-2. Figure 4-1 shows all openings in the computational model.

Table 4-2 Overview doors computational model.

From compartment	Towards compartment	Width [cm]	Height [cm]	Opening [s]	Closing [s]
1.19 Kitchen	1.29 Corridor	80	210	300	320
1.29 Corridor	Outside (imaginary staircase)	90	210	340	350

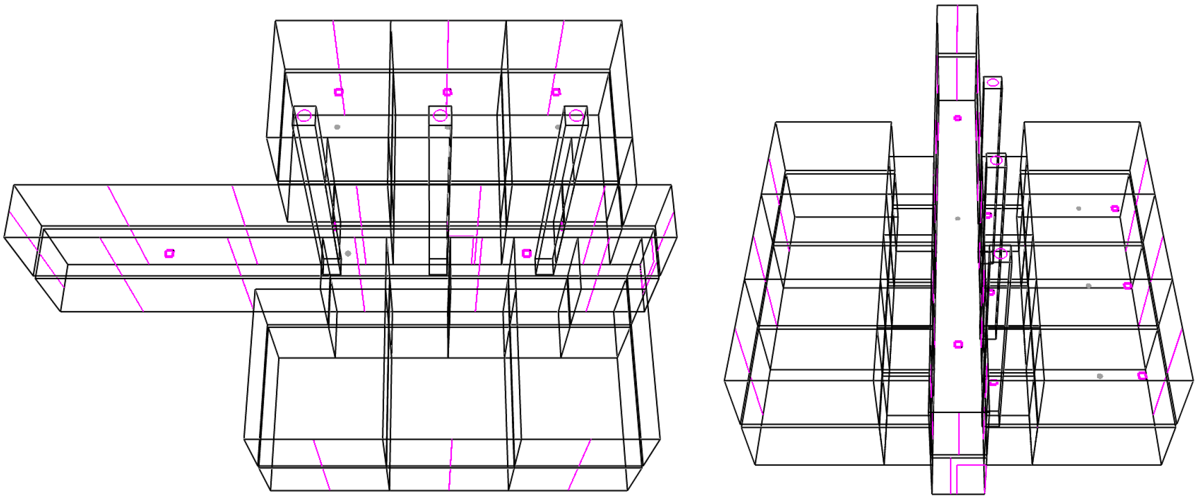


Figure 4-1 Isometries (wire model in 3D) of the simulated situation in Smokeview.

4.1.2 Sensitivity analysis

Sensitivity analysis can be defined as the study of how uncertainty in the outcome of numerical simulations can be attributed to different sources of uncertainty in the model input parameters. It is, therefore, a way to investigate the uncertainty of parameters. The sensitivity analysis examines the effect of a change in one parameter on the outcome of the numerical simulation. The method for performing a quantitative sensitivity analysis is based on earlier research carried out by Van Herpen et al. [30]. The first part of the sensitivity analysis is the determination of the ASET based on the building characteristics and fuel characteristics, as described in appendix 6 (case study).

The sensitivity analysis is used to investigate the uncertainty of parameters within the case study's baseline model. First, the ASET is determined by the conditions in the adjacent compartment based on the acceptable conditions as described in section 2.1.1. An optical density of 0.1 1/m in the adjacent apartments and 0.2 1/m in the corridor. Only the optical density is taken into account since temperature does not exceed the limits. The assessment is not deterministic because there is uncertainty in the boundary conditions regarding building, fuel, and escaping characteristics. The stochastic boundary conditions in this research are:

- Heat of combustion;
- CO Yield;
- Soot Yield;
- Internal airtightness;
- External airtightness;
- Duration opening the front door;
- Moment of opening the front door.

Second, each stochastic parameter is individually varied based on the standard deviation, which results in a specific variance in the ASET [30]. The output is only the optical density since the temperature will not exceed the survivability limit in all cases.

For each stochastic boundary condition (x_i):

- Mean value: $\bar{x}_i$
- Variation: dx_i
- Standard deviation: s_i

For ASET (t):

- Variation: dt
- Specific variation per stochastic: dt/dx_i
- Specific variance per stochastic: $(s_i * dt/dx_i)^2$
- Total variance: $var = \sum_i (s_i * dt/dx_i)^2$
- Standard deviation: $s = \sqrt{var}$

4.1.3 Measures

As a result of the literature research, it is clear that little research has been performed around the stay-in-place concept and associated building and installation technical measures. Various scenarios (Table 4-3) have been simulated to understand their effect on the conditions and find out what are the best measures to prevent smoke propagation and improve the survivability in a senior residential complex.

Table 4-3 Overview of scenario's

Number	Measures
1.1	Airtightness internal
1.2	Airtightness external
1.3	Airtightness internal and external
2	Sprinkler system
3	Ventilation system
4	Pressure release valve
5	Type of fuel

Scenario 1.1: Airtightness internal

- Internal airtightness improvement towards qv;10 of 0.15 $dm^3/s.m^2$.
- The equivalent surface area towards the corridor is decreased to 9.26 cm^2.
- The equivalent surface area towards the outside stays the same.

Scenario 1.2: Airtightness external

- External airtightness improvement towards qv;10 of 0.15 $dm^3/s.m^2$.
- The equivalent surface area towards the outside is decreased to 3.61 cm^2.
- The equivalent surface area towards the corridor stays the same.

Scenario 1.3: Airtightness internal and external

- Apartment airtightness improvement towards qv;10 of 0.15 $dm^3/s.m^2$.
- The equivalent surface area towards the corridor is decreased to 9.26 cm^2.
- The equivalent surface area towards the outside is decreased to 3.61 cm^2.

Scenario 2: Sprinkler system

- Sprinklers are positioned in the kitchen and living room.
- Activation temperature 68 °C (341.15 K).
- RTI is 35 $m \cdot s^{0.5}$.
- Spray density $3.75E^{-05}$ m/s.

Scenario 3: Ventilation system

- Mechanical ventilation deactivates in the apartment of fire origin and the corridor when the setpoint is reached.
- The mechanical ventilation will deactivate exhaust vents in the other apartments in order to create overpressure.
- Deactivation temperature 72 °C (345.15 K).

Scenario 4: Pressure release valve [23]

- Pressure valve with a cross-sectional area of 0.05 m^2.
- Opening by a pressure of 50 Pa [EN 12101-6].

Scenario 5: Type of fuel [35]

- Cellulose fuel with molecular formula $C_4H_6O_3$.
- Heat of combustion is 14 MJ/kg.
- CO yield: pre 0.018 and post 0.17.
- Soot Yield: pre 0.018 and post 0.035.

4.1.4 Concepts

The results of the BIO measures will provide insight into the effect on the optical density and temperature in the adjacent apartment and corridor. It is desirable to form reliable concepts, and therefore different BIO measures are combined within a concept.

It is expected that regulations are based on improved external airtightness, but the internal airtightness is particularly essential in apartments with corridor access. Despite the results of the improved airtightness of the different partition structures, within the concepts, it is assumed that the airtightness of the entire apartment will be improved. This will form the basis of any concept as it will most likely become the new standard in the near future. Table 4-4 gives an overview of the different concepts. These are four concepts based on the results from section 4.2.2

Table 4-4 Overview of concepts.

Number	Measures
1.	1.3 Airtightness apartment + 2. Sprinkler system
2.	1.3 Airtightness apartment + 4. Pressure release valve
3.	1.3 Airtightness apartment + 2. Sprinkler system + 4. Pressure release valve
4.	1.3 Airtightness apartment + 2. Sprinkler system + 5. Type of fuel

4.2 Results

4.2.1 Sensitivity analysis

As described in section 4.1.2, a sensitivity analysis has been applied to the baseline model of the case study. This case study was first deterministically approached in order to determine the ASET. With a sensitivity analysis a probabilistic approach was carried out. The results provide insight into the influence of the various input parameters on the output (ASET).

Deterministic approach

For the baseline model of the case study, the CFAST input data is included in Appendix 6. Figure 4-2 graphically summarizes the simulation results in both the corridor and adjacent apartment. The optical density conditions are used as limit as described in section 2.1.1. The temperature is not included because it does not exceed the limits. The optical density (Figure 4-2) in the corridor exceed the limit of 0.2 [1/m] (sight length 5 meters) after 157 seconds. In the adjacent apartment the limit of 0.1 [1/m] (sight length 10 meters) is exceeded after 352 seconds in the corridor.

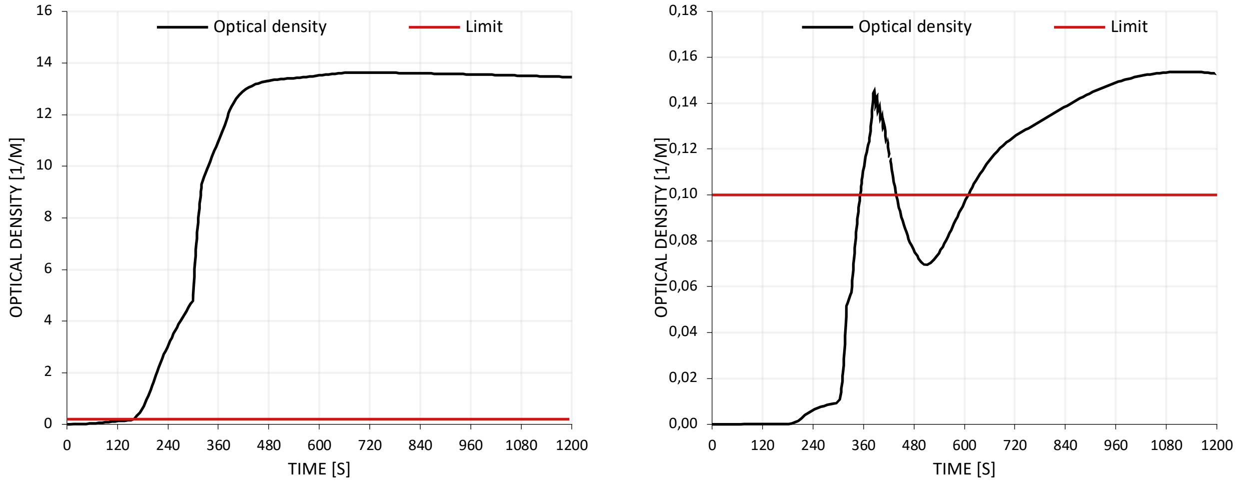


Figure 4-2 Simulations results of the corridor 1.29 (left) and apartment 1.18 (right), optical density criterion assessed.

The limit in the corridor is exceeded before the door from the fire compartment is opened. Which means smoke is propagated through cracks and seams. After opening the door of the fire compartment after 300 seconds, the corridor is completely filled with smoke, which also increases the optical density in the adjacent compartments (Figure 4-2).

Probabilistic approach

The probabilistic approach is performed in order to nuance the results of the deterministic approach. The simulation consists of uncertainty in the boundary conditions which must take into account. An overview of these boundary conditions with the mean values and standard deviations is shown in Table 4-5.

From Table 4-5, it can be concluded that in the corridor and adjacent apartment, the optical density is most dependent on the amount of Soot Yield. Inside the adjacent apartment, the moment opening the front door and the internal airtightness is a determining factor. The result is shown graphically in a cumulative probability distribution of the ASET in Figure 4-3. The complete sensitivity analysis is included in Appendix 7 for the baseline model of the case study.

Table 4-5 Overview of the stochastic parameters, including the mean values and the standard deviations based on Van Herpen et al. [30].

Parameter	**Average**	**Variation V**	**St. deviation s**	**Value x+dx**	**Corridor 1.29 ASET [min]**	**Apartment 1.18 ASET [min]**
Heat of combustion	21.80 [MJ/kg}	+0.20	4.36	26.16	2.62	5.72
		-0.20	-4.36	17.44	2.63	6.00
Moment opening front door	5.00 [min]	+0.15	0.75	5.75	2.62	5.10
		-0.15	-0.75	4.25	2.62	6.23
Duration opening front door	0.33 [min]	+0.20	0.07	0.40	2.62	5.77
		-0.20	-0.07	0.27	2.62	6.02
CO Yield	Pre 0.014, Post 0.051	+0.50	50.00	150.00	2.62	5.87
		-0.50	-50.00	50.00	2.62	5.87
Soot Yield	Pre 0.100, Post 0.210	+0.50	50.00	150.00	2.13	5.55
		-0.50	-50.00	50.00	2.73	6.83
Internal airtightness	0.15 [cm]	+0.50	0.075	0.225	2.62	5.75
		-0.50	-0.075	0.075	2.63	6.38
External airtightness	0.09 [cm]	+0.50	0.045	0.135	2.63	5.97
		-0.50	-0.045	0.045	2.62	5.92

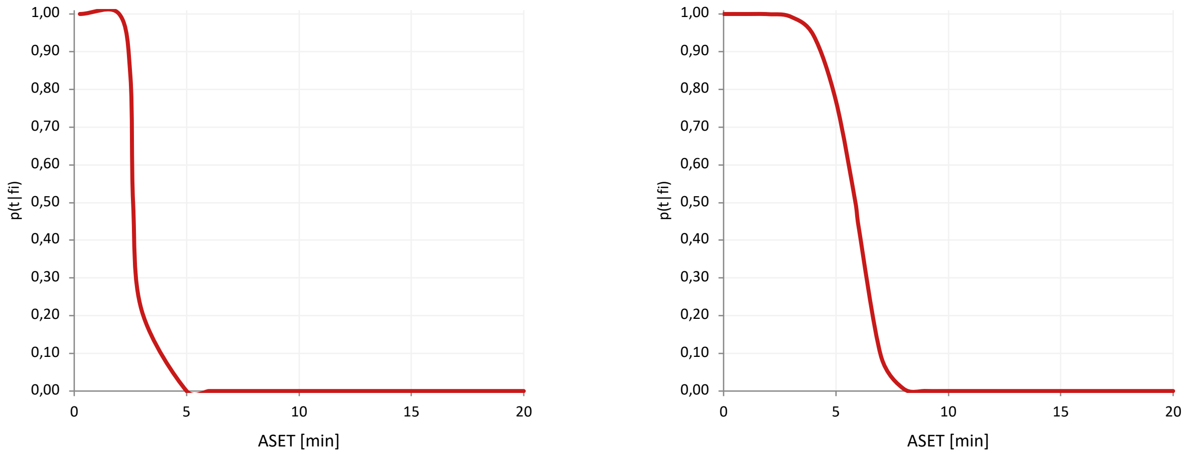


Figure 4-3 Cumulative probability distribution ASET in corridor 1.29 (left) and apartment 1.18 (right), optical density criterion of 0.2 [1/m] in the corridor and 0.1 [1/m] in the apartment.

4.2.2 BIO measures

The results of the baseline simulations are shown in section 4.2.1. They are used for a comparison with the results of the simulations with different measures in order to see the influence on the conditions. The comparison is based on the optical density obtained in apartment 1.18 and the corridor. Also, the upper layer temperature in the corridor is shown. It is assumed that a stratified situation will arise in the corridor and the adjacent apartment a mixed situation since the temperature increase is small.

Scenario 1: Airtightness

Scenario 1 consists of 3 measures regarding the airtightness of the apartment. The optical density in the apartment next to the fire apartment shows widespread in the results (Figure 4-4). With an improved external partition structure, the optical density becomes higher, and thus conditions deteriorate. An improvement of the internal partition structure provides a significantly better situation. The peak of the optical density has been reduced from 0.15 to 0.05 1/m (Table 4-6). With an improvement of both partition structures, the optical density is reduced to 0.09 1/m. Based on these results of measure 1.1 and 1.3, the conditions in the adjacent apartments will comply with the limit of 0.10 1/m.

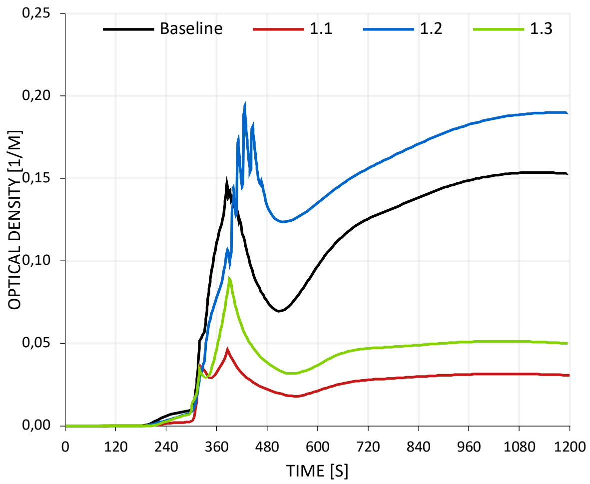
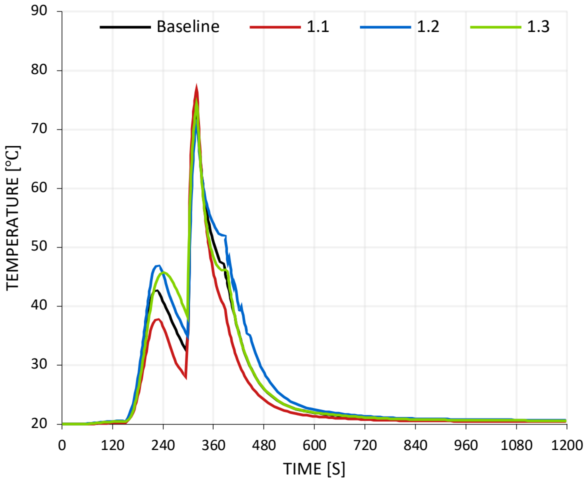


Figure 4-4 Comparison of the optical density [1/m] in apartment 1.18 as a result of different airtightness measures.

In the corridor, changing the airtightness of the partition structures hardly has any effect on the temperature. In the corridor, it varies between 72 and 77 °C (Figure 4-5). The optical density is lower with an internal improvement of the partition structure towards the corridor, but this improvement does not affect the ASET (Table 4-6).



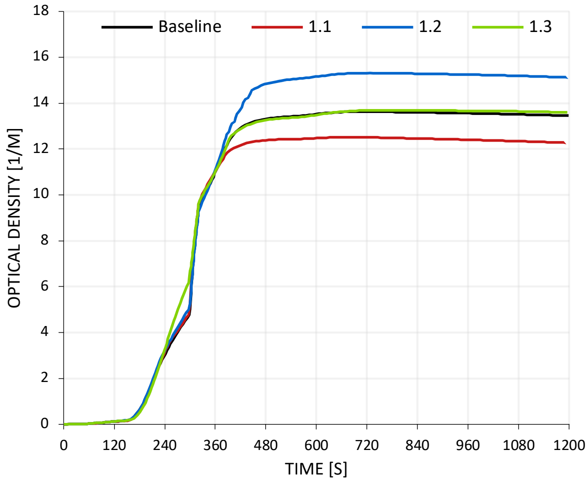


Figure 4-5 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of different airtightness measures.

Table 4-6 Results scenario 1.

Measure	**Compartment**	**Peak value [°C]**	**Optical density [1/m]**	**Sight length [m]**	**ASET [min]**
Baseline model	Apartment 1.18	-	0.15	6.50	5.87
	Corridor 1.29	73.67	13.63	0.07	2.62
1.1 Airtightness	Apartment 1.18	-	0.05	21.54	> Burning time
	Corridor 1.29	76.79	12.52	0.08	2.67
1.2 Airtightness	Apartment 1.18	-	0.20	5.08	6.35
	Corridor 1.29	72.00	15.31	0.07	2.60
1.3 Airtightness	Apartment 1.18	-	0.09	11.10	> Burning time
	Corridor 1.29	74.35	13.68	0.07	2.65

Scenario 2: Sprinkler system

The sprinkler system has a positive effect on the conditions in the adjacent apartment where the optical density decreases to an acceptable value of 0.03 1/m (Table 4-7). Based on these results, the conditions in the adjacent apartments will comply with the limit of 0.10 1/m.

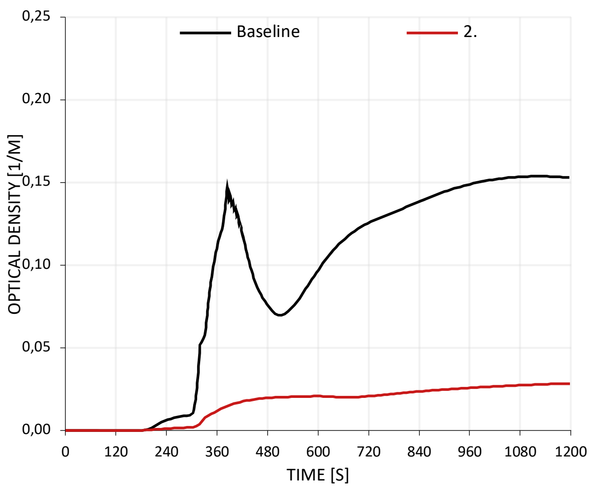


Figure 4-6 Comparison of the optical density [1/m] in apartment 1.18 as a result of a sprinkler system.

This improvement is also noticeable in the corridor. Both the temperature and the optical density are significantly reduced. The maximum temperature has been lowered from 73 to 42 ºC and the optical density from 13.63 to 5.05 1/m (Figure 4-7). Despite this improvement, the optical density in the corridor does not meet the requirement of 0.2 1/m in the corridor (Table 4-7). The ASET in the corridor remains the same as in the baseline situation.

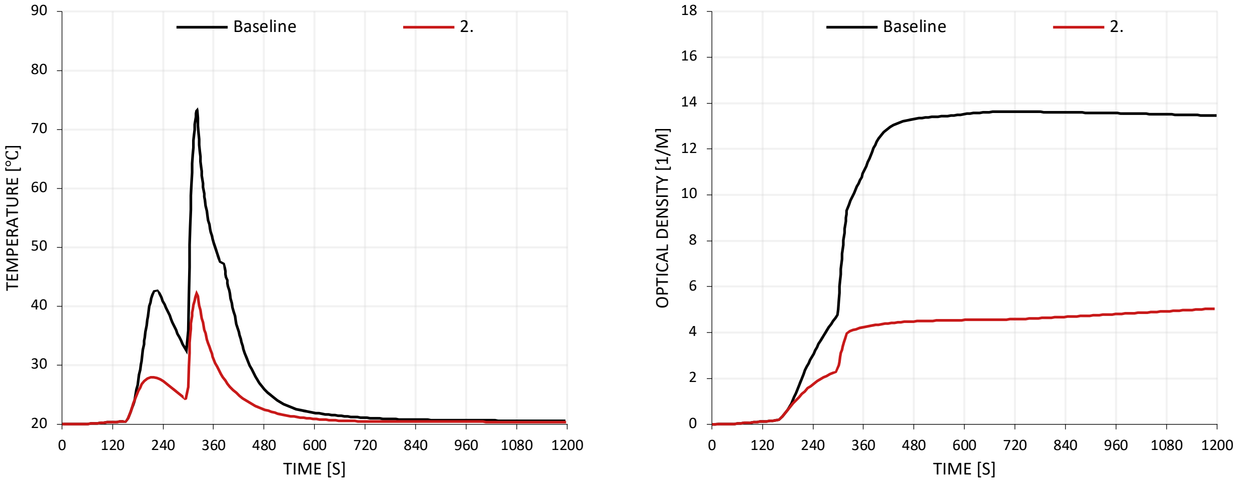


Figure 4-7 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of a sprinkler system.

Table 4-7 Results scenario 2.

Measure	Compartment	Peak value [°C]	Optical density [1/m]	Sight length [m]	ASET [min]
Baseline model	Apartment 1.18	-	0.15	6.50	5.87
	Corridor 1.29	73.67	13.63	0.07	2.62
2. Sprinkler system	Apartment 1.18	-	0.03	35.14	> Burning time
	Corridor 1.29	42.33	5.05	0.20	2.62

Scenario 3: Ventilation system

By adjusting the ventilation system in order to create overpressure in the other apartments except for the apartment of fire origin, no improvement of the conditions is realized. In the adjacent apartment, the first peak to an optical density of 0.15 1/m remains the same as in the baseline scenario. However, after this moment an increase of the optical density due to the ventilation system is noticeable (Figure 4-8). The ASET shows no significant improvement.

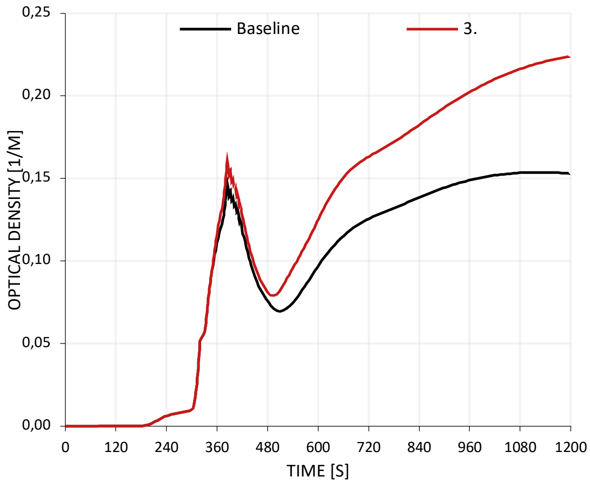


Figure 4-8 Comparison of the optical density [1/m] in apartment 1.18 as a result of a ventilation system.

In the corridor, the temperature is not changing by adjusting the ventilation system, it remains the same as in the baseline situation (Figure 4-9). The optical density has also hardly changed, resulting in a similar ASET as in the baseline situation (Table 4-8).

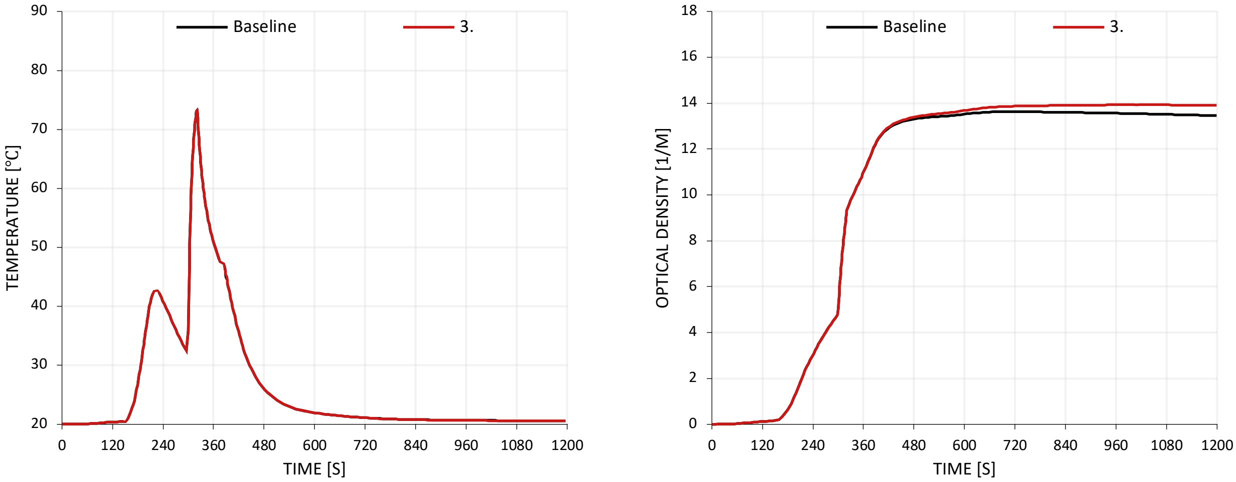


Figure 4-9 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of a ventilation system.

Table 4-8 Results scenario 3.

Measure	Compartment	Peak value [°C]	Optical density [1/m]	Sight length [m]	ASET [min]
Baseline model	Apartment 1.18	-	0.15	6.50	5.87
	Corridor 1.29	73.67	13.63	0.07	2.62
3. Ventilation system	Apartment 1.18	-	0.22	4.46	5.85
	Corridor 1.29	73.67	13.93	0.07	2.62

Scenario 4: Pressure release valve

By implementing a pressure release valve (0.25x0.20 m) in the façade towards the outside, internal smoke propagation is counteracted. The overpressure is decreased and the driving force of smoke propagation is lower. The air, which mainly consists of smoke, is released when the pressure inside the apartment is above 50 Pa. The results show a significant improvement for the optical density in the adjacent apartment compared to the baseline situation (Figure 4-10). The optical density reaches a maximum of 0.08 1/m, which comply with the limit of 0.1 1/m in the apartment (Table 4-9).

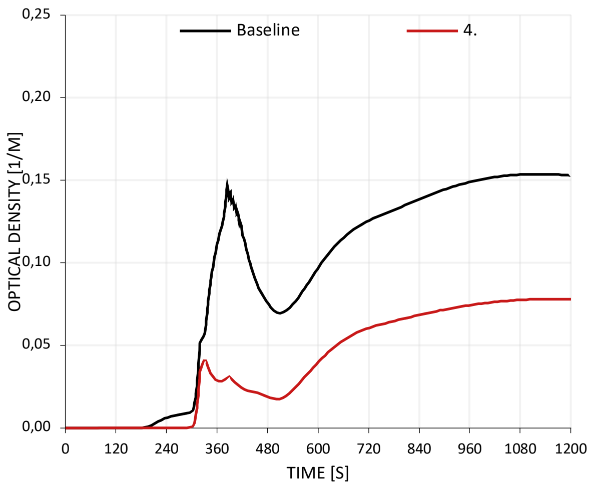


Figure 4-10 Comparison of the optical density [1/m] in apartment 1.18 as a result of a pressure release valve.

The temperature peak, before the front door opens, is lower compared to the baseline situation. As a result, there is less smoke spread in the corridor until the front door is opened (Figure 4-11). The optical density in the corridor has reduced by 50% until the moment of opening the door. The ASET in the corridor has therefore been extended by 0.14 minutes. After opening the door, the optical density remains lower, but this results in a vision length change that is not noticeable (Table 4-9).

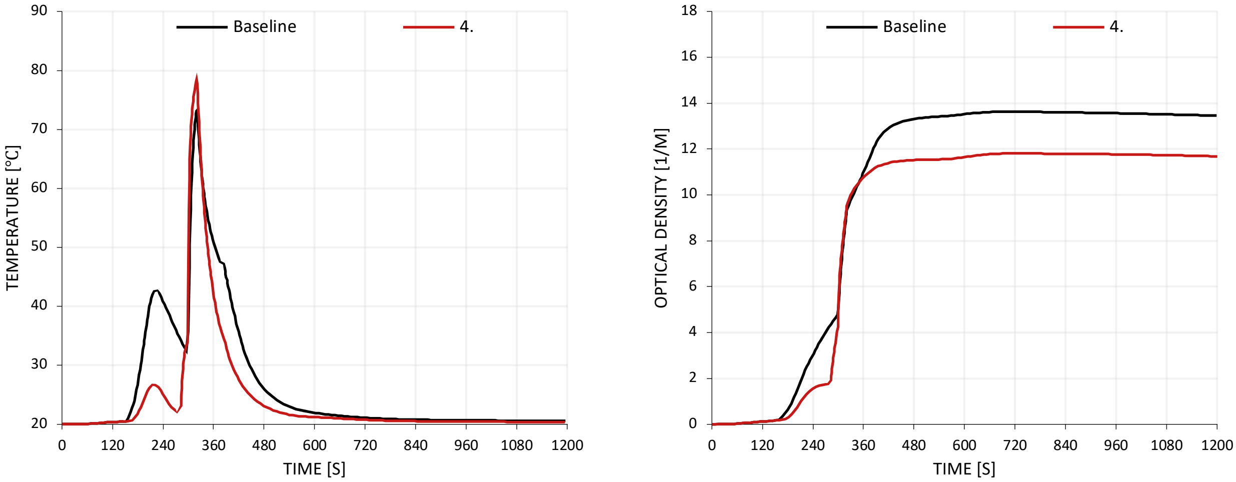


Figure 4-11 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of a pressure release valve.

Table 4-9 Results scenario 4.

Measure	Compartment	Peak value [°C]	Optical density [1/m]	Sight length [m]	ASET [min]
Baseline model	Apartment 1.18	-	0.15	6.50	5.87
	Corridor 1.29	73.67	13.63	0.07	2.62
4. Pressure valve	Apartment 1.18	-	0.08	12.80	> Burning time
	Corridor 1.29	78.46	11.81	0.08	2.78

Scenario 5: Type of fuel

Fuel is one of the main drivers of smoke production, and by changing this component, a direct effect on the result is shown (Figure 4-12). The fuel has been changed to a full cellulose fuel, and this is an ideal situation that will rarely occur in practice. However, it appears that the optical density in the adjacent apartment can be reduced to 0.03 1/m, resulting in a sight length of 32.80 meters (Table 4-10).

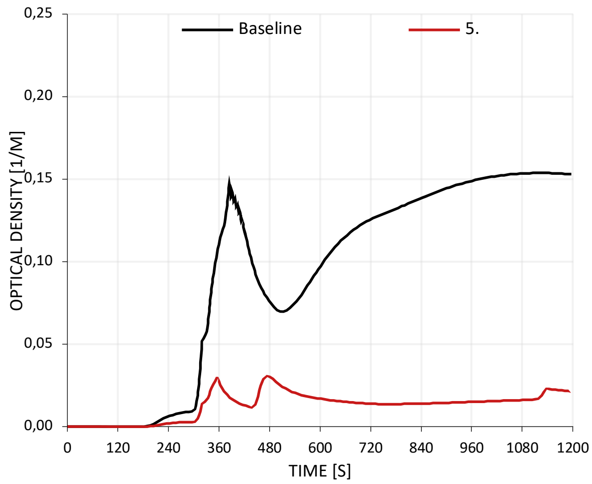


Figure 4-12 Comparison of the optical density [1/m] in apartment 1.18 as a result of the type of fuel.

Adjusting the type of fuel has no effect on the temperature in the corridor, which remains the same as the baseline situation (Figure 4-13). The most significant effect is visible with the optical density, which has been reduced from 13.63 to 3.51 1/m. This is a significant improvement and extends the ASET by 0.41 minutes (Table 4-10).

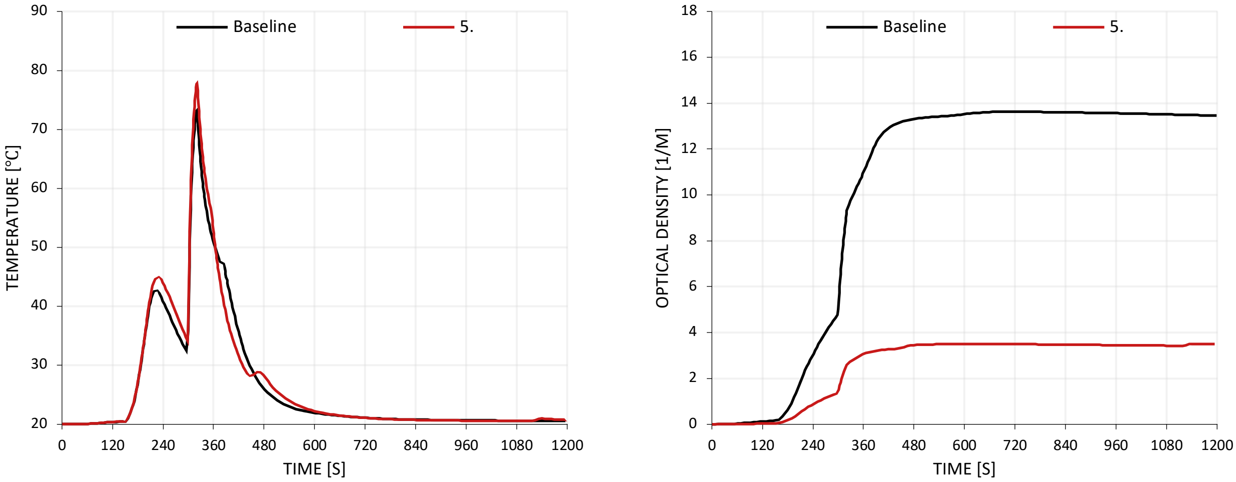


Figure 4-13 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of the type of fuel.

Table 4-10 Results scenario 5.

Measure	Compartment	Peak value [°C]	Optical density [1/m]	Sight length [m]	ASET [min]
Baseline model	Apartment 1.18	-	0.15	6.50	5.87
	Corridor 1.29	73.67	13.63	0.07	2.62
5. Type of fuel	Apartment 1.18	-	0.03	32.80	> Burning time
	Corridor 1.29	78.31	3.51	0.29	3.03

To summarize, from the results of the different scenarios it can be noticed that the ventilation system and an improvement in external airtightness, have a negative effect on the conditions in the different compartments in the building. With the other scenarios, the optical density conditions in the adjacent apartment can be reduced in such a way that they meet the specified requirement of 0.1 1/m. In the corridor, the addition of a sprinkler system and adjustment of the fuel provides significant improvements whereby the optical density is lowered.

4.2.3 Concepts

The results of the concepts (Table 4-11) are presented in the same way as the results in section 4.2.2. In the adjacent apartment, only the optical density will be used because temperature in this apartment is not a threat. The optical density limit used for the adjacent apartment and corridor is described in section 4.2.1.

Adjacent apartment

In all concepts, a mixed situation will occur, similar to the baseline situation. All concepts meet the set limit and the ASET is longer than the burning time of 20 minutes. The concepts with a sprinkler installation prove to be the most effective. Sight lengths of more than 50 meters are achieved by these concepts. In concept two, where no sprinkler installation is used, a visibility length of 42 meters is achieved (Table 4-11).

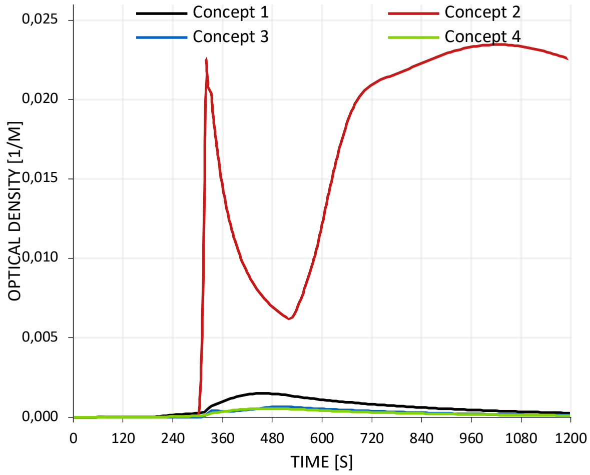


Figure 4-14 Comparison of the optical density [1/m] in apartment 1.18 as a result of the different concepts.

Corridor

The temperature of the hot zone can be decreased to acceptable values of 38 ºC or lower by implementing a sprinkler system (concepts 1, 3, and 4). Concept two has a maximum temperature of almost 80 ºC. The optical density is lowered compared to the baseline situation. However, in no concept, it is below the limit of 0.2 1/m. Concept two shows the highest optical density and concept four the lowest (Figure 4-15). In concept four, the optical density is lowered to 0.64 1/m, which is a sight length of 1.56 meters in the corridor (Table 4-11). The results have to be qualified because they are obtained in the upper layer and not the entire corridor. The smoke layer height varies between 1.60 and 1.95 meters.

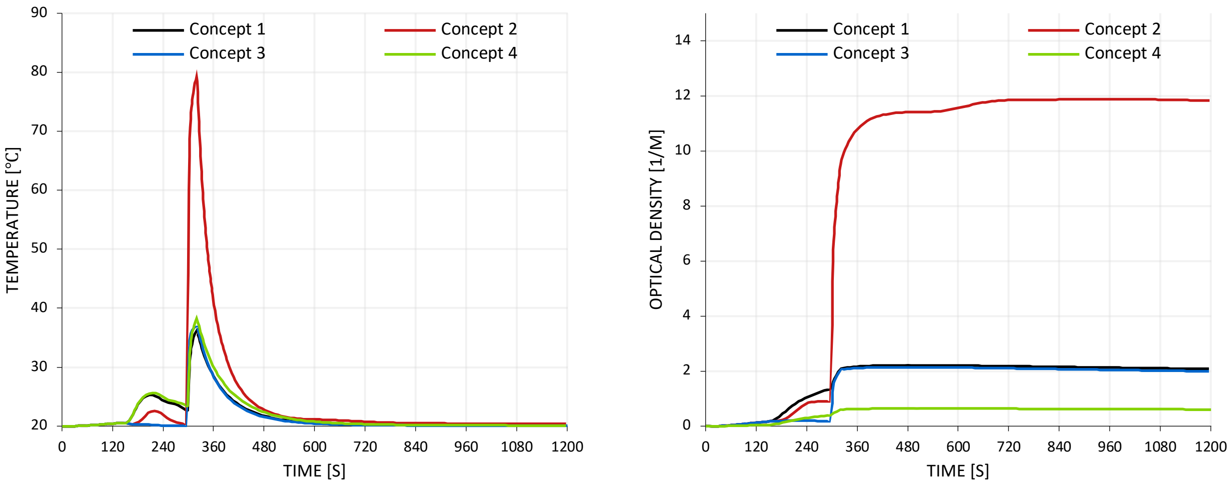


Figure 4-15 Comparison of the temperature [°C] and optical density [1/m] in corridor 1.29 as a result of the different concepts.

Table 4-11 Results concepts.

	Compartment	Peak value [°C]	Optical density [1/m]	Sight length [m]	ASET [min]
Concept 1	Apartment 1.18	-	0.002	> 50	> Burning time
	Corridor 1.29	36.20	2.21	0.45	2.65
Concept 2	Apartment 1.18	-	0.023	42.16	> Burning time
	Corridor 1.29	79.21	11.87	0.08	2.95
Concept 3	Apartment 1.18	-	0.001	> 50	> Burning time
	Corridor 1.29	37.17	2.14	0.47	3.33
Concept 4	Apartment 1.18	-	0.001	> 50	> Burning time
	Corridor 1.29	38.24	0.64	1.56	3.38

To summarize, including concepts with BIO measures, it is possible to obtain the conditions in the adjacent apartments that meet the requirements. A sprinkler system in a concept provides an additional reduction of the optical density. Conditions in the corridor remain highly dependent on the opening of the front door of the apartment of fire origin. This causes smoke to spread towards the corridor resulting in a short ASET. However, the smoke layer height appears to be high enough to be able to escape safely when necessary. Concept four shows the best conditions in the adjacent apartment and corridor. By using this concept, the ASET in the apartment is longer than the burning time and, in de corridor, the ASET is extended by 0.73 minutes. This concept consists of an improved airtightness, a sprinkler system, and a different type of fuel.

4.3 Discussion

The sensitivity analysis is based on an estimate of the standard deviations. With a smaller uncertainty in the standard deviation, the uncertainty of the result will also be smaller. However, this is not possible in the case study because more research needs to be done into the fuel objects in an apartment, the internal airtightness measurements, and human behavior since the model is most dependent these parameters (Table 4-5).

In the simulations, no air leakage to adjacent apartments is defined, only towards the corridor and outside. Therefore, smoke propagation to the adjacent apartment always takes place via the corridor as a result of air leakage and the opening of the front door. In practice, it has been found that this is not always the case because smoke also spreads through ducts and sockets. However, the results do provide insights into the improvement compared to the baseline situation as a result of an applied measure or concept. The results of simulated measures are in line with the expectations described in section 2.1.2. However, only the influence of the ventilation system by creating overpressure is negative on the spatial conditions and different than expected.

The results of the airtightness measures confirm the theory that the produced smoke searches the path of least resistance when the pressure is increased. An improved internal partition structure results in better conditions in the adjacent apartment and corridor compared to an improved external partition structure. However, the regulations only set the airtightness requirements for the floor, façade, and roof of a building as a result of the energy transition. A pressure release valve can be used to reduce the pressure. The results show a reduction in the optical density because smoke propagates through the opening in the façade. The principle corresponds to an improved internal airtightness compared to the external airtightness. However, a valve placed in the façade is not always desirable aesthetically. It could be investigated how a pressure release valve can be combined with a mechanical ventilation system. The internal resistance of the installation must be taken into account, whereby the heat recovery unit is excluded because it creates too much resistance [23].

Applying a sprinkler system provides extra personal safety [30]. This is also found in the results of the simulations. Conditions are obtained in the adjacent apartments that meet the set requirements, causing the ASET to exceed the burning time. This is not the case in the corridor because the ASET is as long as in the baseline model due to internal air leakage. After opening the front door, the most significant difference with the baseline model is visible. The result of this scenario therefore shows that the conditions in adjacent space are within limits, but on the corridor, the limit is exceeded just as quickly. This development can also be noticed when the type of fuel is adjusted. In the corridor, the visibility length remains far below the set limit. These results can be explained because in a residential fire, a resident has to escape and thereby opens the front door. By opening the door, smoke propagates quickly towards the corridor. Reducing smoke production is then a first step that must be taken within the concepts.

The different measures are discussed and by adding these measures together in concepts, better conditions are obtained in the adjacent apartments and corridor during a small fire (sofa). The best conditions, based on the optical density and temperature, are obtained by applying an improved airtightness, a sprinkler system, and a different type of fuel (Concept 4). The explanation for this result can be the type of fuel, which is changed, and according to the results from the measures (Section 4.2.2), it is the most effective measure. The insight obtained with these results is that solutions should not only be found within a single building technical or installation technical measure but a combination of these measures.

5 Discussion

The results interpretation is already discussed and can be found in section 3.3 for the validation study and section 4.3 for the case study.

5.1 Limitations

The limitations found at the start of the study are presented in section 1.5. These are the limitations with regard to the study methodology and available data. In addition, more limitations need to be considered. During the validation study, a direct comparison of the upper layer temperature and oxygen concentrations of the experiments and simulations were used to determine the validity of the simulation. However, a stay-in-place concept can be determined by the temperature and optical density in a specific apartment. Also, using the optical density is a simplified way to determine whether a compartment is survivable during a fire. If the optical density is not satisfactory, it can be assumed that the toxicity of the smoke is too high. However, the optical density is highly dependent on the amount of soot and less on the invisible gas carbon monoxide. Thereby, the zone models predict circumstances of different zones and assume that the conditions are the same for the entire zone, which is not the case in practice.

5.2 Future research

In this study, the first step has been made to investigate whether a stay-in-place concept is feasible. The current problem cannot be solved in this study yet, because there are too many uncertainties. In particular, the reliability of the stay-in-place concept and the uncertainty of the assessment criteria used in this research. The behavior of residents is crucial when applying a stay-in-place concept. This uncertainty has not been included in this study. In this study, it was assumed that a sight length of 10 meters is sufficient to ensure that residents do not attempt to escape. The following research will help reduce this uncertainty:

- Human behavior caused by optical density in their apartment.

This research shows that the type of fuel has a significant effect on smoke production and as a result, the smoke propagation. The study is based on a small fire (sofa) consisting of one type of material. In practice, there is a wide variation between the number of materials and types of materials in an apartment. The following research will help reduce this uncertainty:

- The effect of different types and quantities of materials on smoke production during a fire, inside a senior apartment complex.

As a result of the current energy transition and regulations, external separation constructions are being built more airtight. This results in more internal smoke propagation (Figure 4-4) compared to an improved internal separation construction. Now it appears that internal air leakage has a significant effect on the circumstances, there is still a large uncertainty in the used values. Therefore, it is important to perform the following research:

- Airtightness measurements from different internal partitions constructions in order to determine air leakage towards adjacent apartments.

Research is performed towards pressure release by the use of a mechanical ventilation system. However, more research has to be done in order to draw a conclusion if it is possible to use a mechanical ventilation system as a pressure release valve by which smoke can be extracted in a residential complex. The following research will help to investigate the possibilities:

- Smoke extraction by using a mechanical ventilation system.

6 Conclusion

This research investigated the possibility of applying a stay-in-place concept in a multi-story residential complex has been studied by using numerical simulations. The simulations are based on full-scale experiments performed by IFV/Fire Service Academy in the Schuylenburcht complex in Oudewater, The Netherlands. In this section, the sub-questions will be answered in order to formulate an answer on the main research question.

Sub-question 1: What does a stay-in-place concept entail?
A stay-in-place concept is a non-evacuation strategy. When applying this concept, residents do not have to escape when a fire starts in an adjacent apartment. The conditions in the apartments where there is no fire must comply with the limit for an optical density of 0.1 1/m.

Sub-question 2: Which building technical and installation technical measures are possible to take in order to extend the available safe egress time?
From the results of the simulations, it can be concluded that applying different measures, safe conditions are obtained in adjacent apartments based on temperature and optical density. In the baseline model, an ASET of 5.87 minutes was found. Measures that contribute significantly to the extension of the ASET are an improved internal airtightness, sprinkler system, pressure release valve, and changing the type of fuel. When applying these measures, an ASET is obtained in all situations which is longer than the burning time of 20 minutes. However, none of the measures has a significant effect on the ASET in the corridor except for a changed type of fuel.

Sub-question 3: Which combination of building technical and installation technical measures contribute to a stay-in-place concept in a new multi-story residential complex?
The conceptual approach is a combination of different measures. A conceptual approach results in an improvement in both the adjacent apartments and the corridor. The visibility lengths in the apartments are well within the set limits. Although escaping and evacuating is not intended, it is desirable to improve the conditions in the corridor. By applying an improved airtightness, a sprinkler system, and a different type of fuel (concept 4), the ASET in the corridor is extended from 2.62 to 3.38 minutes, an increase of 29%. The measures used in concept 4 contribute to a stay-in-place concept. It also creates a redundant facility by improving the conditions in the corridor.

Sub-question 4: Is a multizone software model suitable for simulating smoke propagation and which software model is the most accurate?
For the simulations, multizone software was used, which was selected based on a performed validation study. From the validation study, it can be concluded that CFAST is more suitable than B-RISK for fire safety engineering in this case. The results show that the temperature and oxygen concentration in CFAST show better agreement with the experimental data compared to B-RISK.

Based on the results of this research and the answers of all sub-questions, the main research question can be answered and the hypothesis accepted or rejected.

To what extent can a stay-in-place concept be used in a multi-story residential complex in relation to internal smoke propagation?

"*With an approach, based on the current building technical and installation technical possibilities, the application of a stay-in-place concept in a multi-story residential complex is an adequately safe solution*".

Smoke spread is the largest danger in a fire in a multi-story residential complex for elderly people. In this study, it was established that the escape routes fill up with smoke faster than the adjacent apartments. By applying a stay-in-place concept using building technical and installation technical measures, the conditions in adjacent apartments can be kept within limits during a small fire (sofa). Smoke propagation can be significantly reduced by changing the type of fuel, improving the internal airtightness and/or adding a sprinkler system.

Based on these results a stay-in-place concept is possible, and it results in an adequately safe solution for elderly people. The hypothesis can be accepted. However, more research should be performed to limit the uncertainty in the results as described in section 5.2.

7 References

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8 Appendix

1. Theoretical background – Evacuation concept Dutch Building Code
2. Experimental set-up Schuylenburcht complex
3. Top 32 substances in smoke with hazard classification per absorption route
4. Airtightness measurements performed by Nieman
5. Input values validation models
6. Case study baseline model
7. Sensitivity analysis

1. Theoretical background – Evacuation concept Dutch Building Code

The Dutch Building Code 2012 (BB 2012) contains rules and regulations about building constructions, building services and fire safety installations [17]. All buildings in the Netherlands, such as homes, offices, shops, and hospitals, must at least comply with these rules. The requirements of BB 2012 based on fire safety are aimed at two main objectives:

- In case of a fire in a building, those who are present must be able to escape safely;
- The fire may not spread to another object.

The goal is to keep the fire manageable so that everyone can escape safely. In other words: BB 2012 ensures that everyone is out of the building on time and that the surrounded objects do not catch fire. When the building complies with BB 2012 – and no more than that – then there is a good chance that the entire structure will be lost in the case of a fire. Issues such as business continuity, damage to one's property and household effects or social damage (such as monuments) are not part of the building regulations. The building owner has the choice between a burn-down scenario (with the regulations of BB 2012) and a fire resilient building (less damage, no burn-down scenario).

The evacuation concept based on BB 2012 does not take more strict measures when it comes to a senior residential complex; these buildings have a residential function. The concept consists of regulations depending on the characteristics of the residential building. A residential complex with a corridor and four floors must meet following the general requirements:

- Construction of the building may only collapse after 90 minutes of fire;
- The maximum distance of the escape route is 30 meters;
- Compartmentation and sub compartmentation;
- The corridor is a protected escape route and has a fire-resistance requirement of 30 minutes;
- The staircases are extra protected escape routes.

According to BB2012, the spread of fire can be restricted by sub-dividing buildings into three types of compartments. The fire compartment is intended as a maximum fire expansion area. The sub-fire compartment is a part of a fire compartment intended for limiting the spread of smoke and further limiting the range of fire extension. The protected sub-fire compartment is a part of a sub-fire compartment that offers more protection against fire and smoke than a sub-fire compartment and applied to user function of sleeping. The corridor, which is a common traffic area adjacent to the apartments, is an extra protected escape route and falls outside the fire compartment (Figure 1).

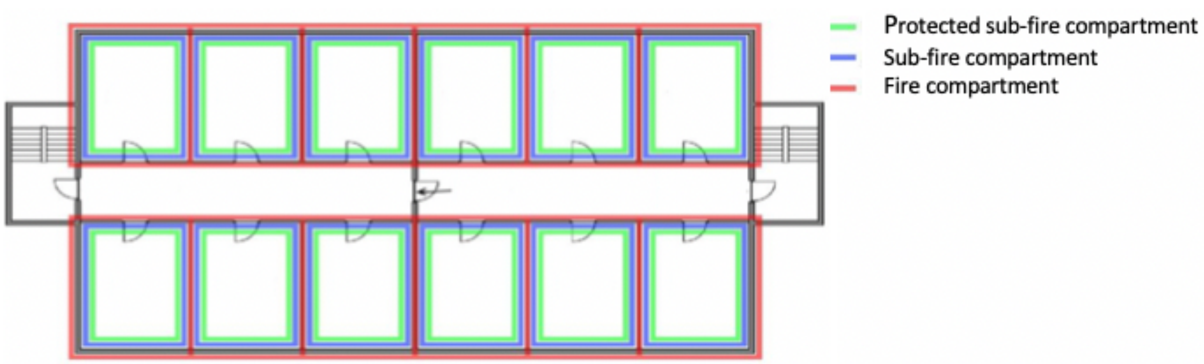


Figure 1 Floorplan with compartmentation according to BB 2012 for residential functions [15]

In addition to BB 2012, The Besluit bouwwerken leefomgeving 2018 (Bbl 2018 (Dutch)) introduced. It contains regulations for smoke permeability [16]. Smoke permeability is the extent to which a structural component lets smoke passage under normalized conditions. The smoke permeability must be determined for each structural component, and the requirements set in NEN 6075 must be met. According to articles 4.63, 4.64 and 4.76, the smoke permeability between different compartments must comply with Sa or S200 [16]. Sa and S200 mean that the smoke passage must be checked for smoke permeability. Criterion Sa is the smoke permeability at low temperatures (20°C). S200 is the smoke permeability at high temperatures (200°C). A structural component with criterion S200 must also comply with Sa. The resistance to the smoke passage between two compartments is Sa or S200 if all smoke distribution paths between these compartments pass through at least one structural component with smoke permeability Sa or S200 [16]. The NEN 6075 states that it is possible to choose per construction component, whether the resistance to smoke passage can be determined based on smoke resistance or smoke permeability. As of Bbl 2018, the smoke passage may only be determined using smoke permeability [14].

2. Experimental set-up Schuylenburcht complex

The experimental set-up of the validation is based on the experiment performed in the Schuylenburcht complex in Oudewater (Figure 2). The residential complex was built around 1970. In these times, residential buildings were built according to a fixed pattern, and repetition was the hallmark. That is also visible in Schuylenburcht; a lot of standardization is used. The building has four layers and a corridor on each floor. During the experiments, a part in the building is still operative as a hospice. The other part is empty but was used for housing of the elderly people. It is a building with corridor structure with four floors. For the experiments, the apartments on the first floor will be used. Apartments alongside and above are used for measurement equipment.

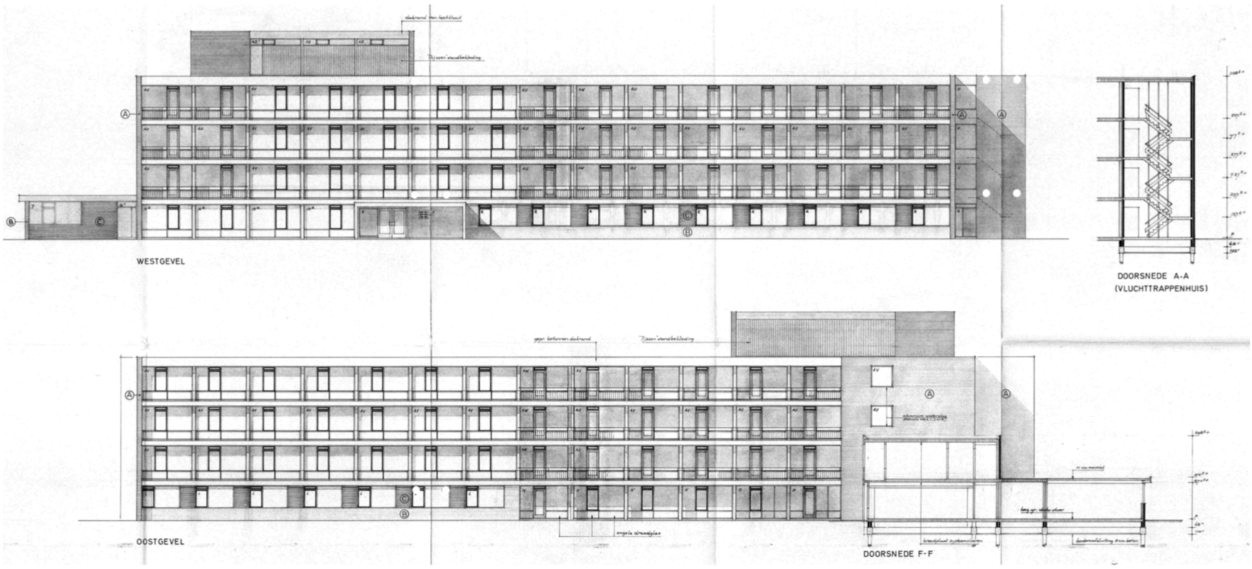


Figure 2 Façades and intersection of the Schuylenburcht complex [20]

The load-bearing structure is made of concrete with concrete slab system floors. Balconies and galleries are supported on concrete consoles. The non-load-bearing partition structure in this building consists of, the facade and the inner walls. The facades are adjusted, the English wire glass is removed from the parapet and replaced by a closed panel. The facade consists of a wooden frame with a large surface of double glazing. There are one door and a flap window present (Figure 3).


Figure 3 Non-load-bearing façade with the parapet closed panel

Inner walls without doors and windows consist of masonry. The walls have a thickness of 120 mm. In this wall are his frames with the front door of the apartment. Above the door is a window, and the rest of the frame is closed with a wooden panel with insulation material (Figure 4).

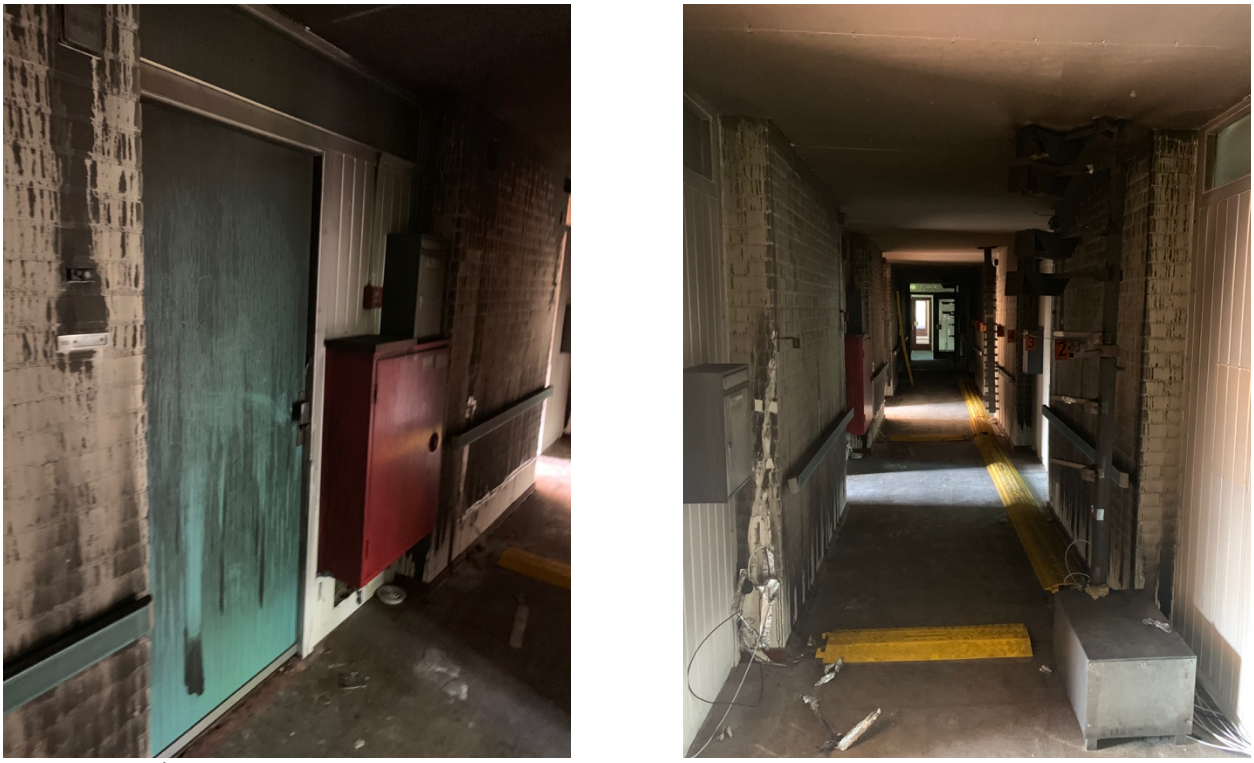


Figure 4 Front door of the apartment at the corridor

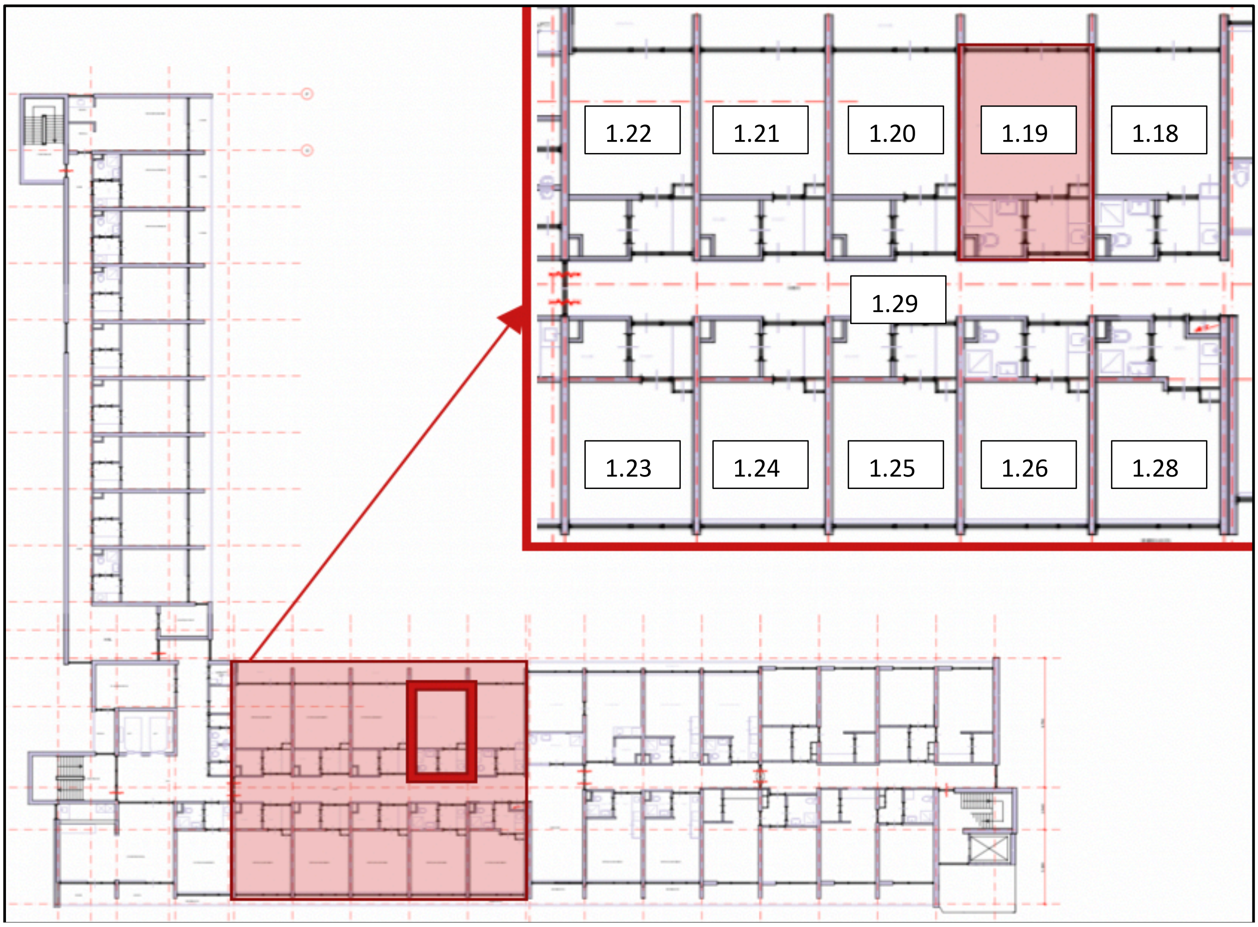


Figure 5 Floorplan first floor of the Schuylenburcht complex, room of fire origin is highlighted [20]

3. Top 32 substances in smoke with hazard classification per absorption route [39]

Chemical name	**Respiration** Occasional exposure	**Respiration** Repeated exposure	**Skin** Occasional exposure	**Skin** Repeated exposure	**Oral** Repeated exposure
CO – Carbon monoxide					
NO2 – Nitrogen dioxide					
HCN – Blue acid					
SO2 – Sulphur dioxide					
HCL – Hydrochloric acid					
Benzene					
Styrene					
Xylene					
Toluene					
Ethylbenzene					
Hexane					
(mono) Chlorobenzene					
Phenol					
Acrolein					
Formaldehyde					
Acetaldehyde					
TDI – 2,4-toluene di-isocyanate					
Methyl isocyanate					
Phenyl isocyanate					
Phosgene					
Perfluoroisobutene (PFIB)					
HF – Hydrogen fluoride					
Ultrafine dust/nanoparticles					
PM 2.5					
PM 10					
Benzo [a] pyrene					
Pyrene					
TCDD (Tetrachlorodibenzodiozine)					
Furan					
Dibenzofuran					
Lead					
Phosphorous pentoxide					

Hazard class	**Respiration** Occasional exposure	**Respiration** Repeated exposure	**Skin** Occasional exposure	**Skin** Repeated exposure	**Oral** Repeated exposure
	No danger	No danger	No skin absorption	No skin absorption	No danger
	Little danger	Poisonous	Skin absorption possible	Possible harmful	Small danger
	Dangerous	Harmful	Skin absorption important	Possible carcinogenic	Harmful
	Deadly	Carcinogenic	Not applicable for smoke	Proven carcinogenic	Not applicable for smoke

4. Airtightness measurements performed by Nieman [22]

Table 1 Air leakage of internal and external partition construction

Apartment	Total: Qv10 dm³/s [Leakage area cm²; n]	Internal: Qv10 dm³/s [Leakage area cm²]	External: Qv10 dm³/s [Leakage area cm²]	Internal/ external difference
1.19 Ventilation duct open	80 dm³/s [164 cm²; 0.56]	-	-	Distribution to be made by user based on the mentioned distribution
1.19 Ventilation duct closed	43 dm³/s [61 cm²; 0.68]	-	-	-
1.20 Ventilation duct open	88 dm³/s [191 cm²; 0.65]	-	-	-
1.20 Ventilation duct closed	41 dm³/s [54 cm²; 0.71]	41 dm³/s [54 cm²]	Foil used to cover the external construction	-
1.20 Ventilation duct closed	67 dm³/s [125 cm²; 0.59]	41 dm³/s (61%) [54 cm²]	26 dm³/s (39%) [71 cm²]	Based on the difference between situation with and without foil
1.21 Ventilation duct open	111 dm³/s [227 cm²; 0.56]	94 dm³/s (85%) [193 cm²]	17 dm³/s (15%) [34 cm²]	Based on inventory and experts.
1.21 Ventilation duct closed	95 dm³/s [136 cm²; 0.68]	81 dm³/s [116 cm²]	14 dm³/s [20 cm²]	Calculated with 85/15

Evaluation results

In apartment 1.21, the air leaks have been inventoried in order to be able to estimate the distribution between internal and external air leaks and to gain insight into the position of the air leaks. It has always been added whether it is an internal or external air leak with a dimensionless numerical indication for the estimated contribution to the total air permeability. One of the estimates of the internal/ external ratio is based on this.

During the measurement, it was found in apartment 1.20 that the feedthrough of a measuring cable (IFV) was not sealed. This makes the external air leaks larger. Due to the lack of large leaks in the entrance patio, the internal leaks are smaller than in apartment 1.21. The ratio internal/external therefore differs from apartment 1.21.

The smoke test in apartment 1.20 shows the same image of smoke distribution as 1.21, except that the distribution to the common corridor was less and little smoke emission was observed through the balcony facade. A large air leak was found at the bottom of the sidelight of the front door in apartment 1.19.

Conclusion

The air permeability of the apartments in the Schuylenburcht complex in Oudewater shows a wide variation, caused by specific differences in particular in the internal partition constructions. The ratio of the internal/external air permeability therefore also differs per apartment, but in all cases, the internal leakage is greater than the external leakage.

In the event of a fire in an apartment, smoke will spread to the communal circulation space and to a lesser extent to the adjacent apartments.

NIEMAN®

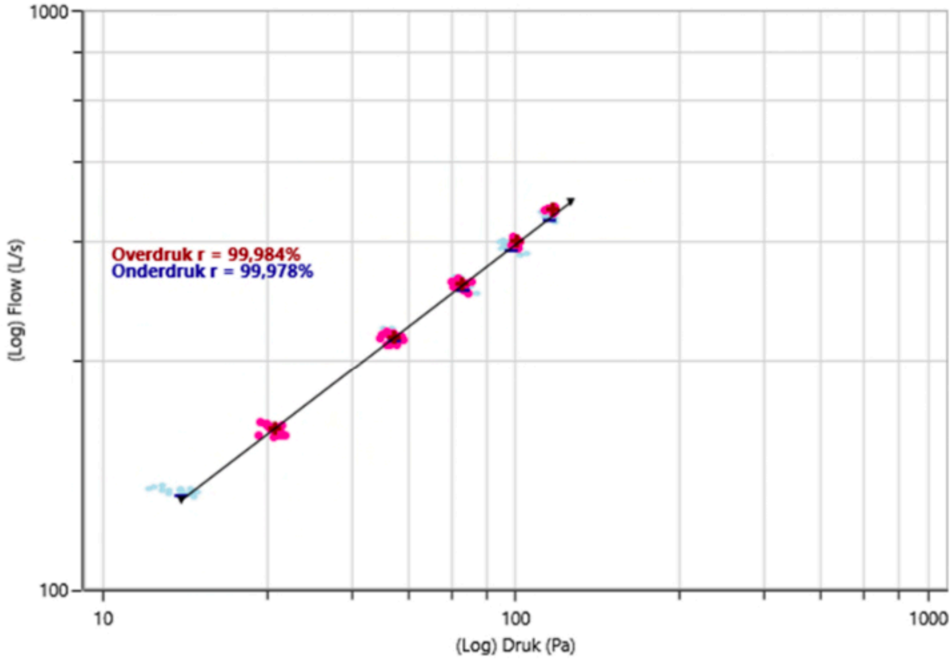
DE RAADGEVENDE INGENIEURS

LUCHTDOORLATENDHEIDSMETING

conform NEN 2686:1988+A2:2008

Projectgegevens:	Vierstroom-Schuylenburcht te Oudewater woning 01.21 Ventilatie afvoeren open
Opdrachtgever:	Instituut Fysieke Veiligheid - Nederland
Meting uitgevoerd door:	A.M. Meulenkamp
Referentienummer:	20190565

Gemeten druk in Pascal in combinatie met de luchtvolumestroom in L/s



MEETRESULTATEN

Onderdruk

Stromingsexponent (n)	0,531
Luchtdoorlatendheidscoëfficiënt (CL)	34,199 L/s
Luchtdoorlatendheidscoëfficiënt (Cenv)	33,987 L/s
Correlatiecoëfficiënt	99,978 r%
Luchtvolumestroom bij 10 Pa, V_{10}	116,188 L/s
Luchtdoorlatendheid	11,6188 L/s/m²

Overdruk

Stromingsexponent (n)	0,560
Luchtdoorlatendheidscoëfficiënt (C)	30,696 L/s
Luchtdoorlatendheidscoëfficiënt (Cenv)	30,772 L/s
Correlatiecoëfficiënt	99,984 r%
Luchtvolumestroom bij 10 Pa, V_{10}	111,458 L/s
Luchtdoorlatendheid	11,1458 L/s/m²

Gemiddeld

Luchtvolumestroom bij 10 Pa, V_{10}	113,80 L/s

GEBOUWGEGEVENS

Gebruiksoppervlak:	10 m^2	(Gebruiksoppervlak A_g)

TESTGEGEVENS Onderdruk

Gemeten met:	Retrotec 6000				
Meting uitgevoerd door:	A.M. Meulenkamp				
Meting uitgevoerd op:	Onderdruk				
Datum:	2019-06-07	Tijd:	10:04	tot	10:16

OMGEVINGSCONDITIES

	Voor de meting	Na de meting
Onderdruk		
Temperatuur binnen	21 °C	21 °C
Temperatuur buiten	15,5 °C	15,5 °C
Windsnelheid	2. lichte wind	2. lichte wind
Barometrische druk:	101,1 KPa	

MEETWAARDEN

Basis drukverschil	Voor de meting (Pa)	Na de meting (Pa)
Onderdruk		
ΔP_{01}	4,57	2,70
ΔP_{01-}	-1,13	-0,90
ΔP_{01+}	5,20	2,95

Drukverschil (ΔP_{gevel})	Luchtvolumestroom (q_v)	Luchtvolumestroom (q_v)	Onnauwkeurigheid
Onderdruk			
19,0 Pa	145,66 dm^3/s	524,38 m^3/h	0,6%
54,0 Pa	270,18 dm^3/s	972,65 m^3/h	-0,8%
77,4 Pa	330,37 dm^3/s	1189,33 m^3/h	-1,0%
100,4 Pa	386,74 dm^3/s	1392,26 m^3/h	0,3%
123,3 Pa	435,84 dm^3/s	1569,02 m^3/h	1,0%
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	
Pa	dm^3/s	0,0 m^3/h	

TU/e

GEBOUWGEGEVENS

Gebruiksoppervlak:	10 m^2	(Gebruiksoppervlak A_g)

TESTGEGEVENS Overdruk

Gemeten met:					
Meting uitgevoerd door:	A.M. Meulenkamp				
Meting uitgevoerd op:	Overdruk				
Datum:	2019-06-07	Tijd:	09:54	tot	10:02

OMGEVINGSCONDITIES

	Voor de meting	Na de meting
Overdruk		
Temperatuur binnen	21 °C	21 °C
Temperatuur buiten	15,5 °C	15,5 °C
Windsnelheid	2. lichte wind	2. lichte wind
Barometrische druk:	101,1 KPa	

MEETWAARDEN

Basis drukverschil	Voor de meting (Pa)	Na de meting (Pa)
Overdruk		
ΔP_{01}	2,29	4,38
ΔP_{01-}	-0,65	0,00
ΔP_{01+}	2,50	4,38

Drukverschil (ΔP_{gevel})	Luchtvolumestroom (q_v)	Luchtvolumestroom (q_v)	Onnauwkeurighei d
Overdruk			
-22,5 Pa	190,93 dm³/s	687,35 m³/h	0,4%
-46,9 Pa	274,95 dm³/s	989,82 m³/h	-0,4%
-70,1 Pa	340,01 dm³/s	1224,04 m³/h	-0,4%
-96,4 Pa	402,85 dm³/s	1450,26 m³/h	-0,5%
-118,5 Pa	457,18 dm³/s	1645,85 m³/h	0,9%
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	
Pa	dm³/s	0,0 m³/h	

5. Input values validation models

CFAST

Release Version : CFAST 7.4.2

OVERVIEW

Compartments	Doors, ...	Ceil. Vents, ...	MV Connects
6	22	1	0

Simulation Time (s)	Output Interval (s)	Smokeview Interval (s)	Spreadsheet Interval (s)
1200.00	1.00	1.00	1.00

AMBIENT CONDITIONS

Interior Temperature (C)	Interior Pressure (Pa)	Exterior Temperature (C)	Exterior Pressure (Pa)
27.	101300.	27.	101300.

COMPARTMENTS

Compartment Name	Width (m)	Depth (m)	Height (m)	Floor (m)	Ceiling Height (m)
119 Woonkamer	3.60	4.27	2.60	3.00	5.60
119 Keuken	1.80	1.60	2.60	3.00	5.60
126 Woonkamer	3.60	4.27	2.60	3.00	5.60
126 Keuken	1.80	1.60	2.60	3.00	5.60
129.1 Corridor	19.00	1.70	2.60	3.00	5.60
Schacht 9	0.60	0.60	9.40	2.20	11.60

VENT CONNECTIONS

Wall Vents (Doors, Windows, ...)

From Compartment	To Compartment	Vent Number	Width (m)	Sill Height (m)	Soffit Height (m)
119 Woonkamer	Outside	1	0.00	0.00	2.60
119 Keuken	119 Woonkamer	2	1.80	0.00	2.60
119 Keuken	129.1 Corridor	3	0.80	0.00	2.10
126 Woonkamer	Outside	4	0.00	0.00	2.60
126 Keuken	126 Woonkamer	5	1.80	0.00	2.60
126 Keuken	129.1 Corridor	6	0.00	0.00	2.60
129.1 Corridor	Outside	7	0.01	0.00	2.60
129.1 Corridor	Outside	8	0.01	0.00	2.60
Schacht 9	Outside	9	0.10	0.00	0.10
Schacht 9	119 Keuken	10	0.10	2.70	2.80
Schacht 9	Outside	11	0.10	5.60	5.70
119 Keuken	129.1 Corridor	12	0.00	0.00	2.60
129.1 Corridor	Outside	13	0.90	0.00	2.10
Schacht 9	Outside	14	0.10	8.40	8.50
129.1 Corridor	Outside	15	0.00	0.00	2.60
129.1 Corridor	Outside	16	0.00	0.00	2.60

129.1 Corridor	Outside	17	0.04	0.00	2.60
129.1 Corridor	Outside	18	0.00	0.00	2.60
129.1 Corridor	Outside	19	0.00	0.00	2.60
129.1 Corridor	Outside	20	0.00	0.00	2.60
129.1 Corridor	Outside	21	0.00	0.00	2.60
129.1 Corridor	Outside	22	0.00	0.00	2.60

Ceiling and Floor Vents

Top Compartment	Bottom Compartment	Vent Number	Shape	Area (m^2)
Outside	Schacht 9	1	Square	0.10

There are no mechanical flow connections

VENT RAMPS

From Compartment	To Compartment	Vent Number		(s)	(s)	(s)	(s)	(s)
119 Keuken	129.1 Corridor	3	Time	0	299	300	1200	
			Fraction	0.00	0.00	1.00	1.00	
129.1 Corridor	Outside	13	Time	0	319	320	330	331
			Fraction	0.00	0.00	1.00	1.00	0.00
Schacht 9		1	Time	0	1200			
			Fraction	1.00	1.00			

THERMAL PROPERTIES

Compartment	Ceiling	Wall	Floor
119 Woonkamer	CONCRETE	NM 2	CONCRETE
119 Keuken	CONCRETE	NM 2	CONCRETE
126 Woonkamer	CONCRETE	NM 2	CONCRETE
126 Keuken	CONCRETE	NM 2	CONCRETE
129.1 Corridor	CONCRETE	NM 2	CONCRETE
Schacht 9	CONCRETE	NM 2	CONCRETE

Name	Conductivity	Specific Heat	Density	Thickness	Emissivity
NM 2	0.800	840.	2.100E+03	0.200	0.900
CONCRETE	1.75	1.000E+03	2.200E+03	0.200	0.940
DEFAULT	0.120	00.	800.	1.200E-02	0.900

FIRES

Compartment	Fire Type	Position (x,y,z)	Relative Humidity	Lower O2 Limit	Radiative Fraction
119 Woonkamer	Constrained	1.00,1.00,0.45	70.0	10.00	0.30

Chemical formula of the fuel

Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
9.000	16.000	3.000	1.400	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	2.18E+07	0.0	0.45	0.10	1.40E-02	0.20	0.0	0.0
50.	2.29E-04	2.18E+07	5.00E+03	0.45	0.10	1.40E-02	0.20	0.0	0.0
100.	4.59E-04	2.18E+07	1.00E+04	0.45	0.10	1.40E-02	0.20	0.0	0.0
150.	4.59E-04	2.18E+07	1.00E+04	0.45	0.10	1.40E-02	0.20	0.0	0.0
200.	1.28E-02	2.18E+07	2.78E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
250.	1.46E-02	2.18E+07	3.18E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
300.	1.61E-02	2.18E+07	3.50E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
350.	2.81E-02	2.18E+07	6.13E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
370.	3.28E-02	2.18E+07	7.15E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
400.	5.50E-02	2.18E+07	1.20E+06	0.45	0.10	1.40E-02	0.20	0.0	0.0
450.	5.91E-02	2.18E+07	1.29E+06	0.45	0.10	1.40E-02	0.20	0.0	0.0
500.	4.59E-02	2.18E+07	1.00E+06	0.45	0.21	5.10E-02	0.20	0.0	0.0
550.	3.73E-02	2.18E+07	8.13E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
600.	3.58E-02	2.18E+07	7.80E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
700.	1.30E-02	2.18E+07	2.83E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
750.	7.43E-03	2.18E+07	1.62E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
1200.	1.83E-03	2.18E+07	4.00E+04	0.45	0.21	5.10E-02	0.20	0.0	0.0

B-RISK

```
Simulation Time = 1200.00 seconds.
Initial Time-Step = 1.00 seconds.

Room 1

====================================================================
Description of Rooms
====================================================================
Room 1 : 119 Woonkamer
         Room Length (m) =                                  3.60
         Room Width (m) =                                   4.27
         Maximum Room Height (m) =                          2.60
         Minimum Room Height (m) =                          2.60
         Floor Elevation (m) =                              3.000
         Absolute X Position (m) =                          14.400
         Absolute Y Position (m) =                          9.170
         Room 1 has a flat ceiling.
         Shape Factor (Af/H^2) =                            2.3

         Wall Surface is brick
         Wall Density (kg/m3) =                             1600.0
         Wall Conductivity (W/m.K) =                        0.690
         Wall Specific Heat (J/kg.K) =                      840
         Wall Emissivity =                                  0.88
         Wall Thickness (mm) =                              200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         963

         Ceiling Surface is concrete
         Ceiling Density (kg/m3) =                          2300.0
         Ceiling Conductivity (W/m.K) =                     1.200
         Ceiling Specific Heat (J/kg.K) =                   880
         Ceiling Emissivity =                               0.50
         Ceiling Thickness (mm) =                           200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

         Floor Surface is concrete
         Floor Density (kg/m3) =                            2300.0
         Floor Conductivity (W/m.K) =                       1.200
         Floor Specific Heat (J/kg.K) =                     880
         Floor Emissivity =                                 0.50
         Floor Thickness = (mm)                             200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

Room 2 : 119 Keuken
         Room Length (m) =                                  1.80
         Room Width (m) =                                   1.60
         Maximum Room Height (m) =                          2.60
         Minimum Room Height (m) =                          2.60
         Floor Elevation (m) =                              3.000
         Absolute X Position (m) =                          16.200
         Absolute Y Position (m) =                          7.570
         Room 2 has a flat ceiling.
         Shape Factor (Af/H^2) =                            0.4

         Wall Surface is brick
         Wall Density (kg/m3) =                             1600.0
         Wall Conductivity (W/m.K) =                        0.690
         Wall Specific Heat (J/kg.K) =                      840
         Wall Emissivity =                                  0.88
         Wall Thickness (mm) =                              200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         963

         Ceiling Surface is concrete
```

```
        Ceiling Density (kg/m3) =                          2300.0
        Ceiling Conductivity (W/m.K) =                     1.200
        Ceiling Specific Heat (J/kg.K) =                   880
        Ceiling Emissivity =                               0.50
        Ceiling Thickness (mm) =                           200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

        Floor Surface is concrete
        Floor Density (kg/m3) =                            2300.0
        Floor Conductivity (W/m.K) =                       1.200
        Floor Specific Heat (J/kg.K) =                     880
        Floor Emissivity =                                 0.50
        Floor Thickness = (mm)                             200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

Room 3 : 126 Woonkamer
        Room is modelled as a single zone.
        Room Length (m) =                                  3.60
        Room Width (m) =                                   4.27
        Maximum Room Height (m) =                          2.60
        Minimum Room Height (m) =                          2.60
        Floor Elevation (m) =                              3.000
        Absolute X Position (m) =                          14.400
        Absolute Y Position (m) =                          0.000
        Room 3 has a flat ceiling.
        Shape Factor (Af/H^2) =                            2.3

        Wall Surface is brick
        Wall Density (kg/m3) =                             1600.0
        Wall Conductivity (W/m.K) =                        0.690
        Wall Specific Heat (J/kg.K) =                      840
        Wall Emissivity =                                  0.88
        Wall Thickness (mm) =                              200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         963

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                          2300.0
        Ceiling Conductivity (W/m.K) =                     1.200
        Ceiling Specific Heat (J/kg.K) =                   880
        Ceiling Emissivity =                               0.50
        Ceiling Thickness (mm) =                           200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

        Floor Surface is concrete
        Floor Density (kg/m3) =                            2300.0
        Floor Conductivity (W/m.K) =                       1.200
        Floor Specific Heat (J/kg.K) =                     880
        Floor Emissivity =                                 0.50
        Floor Thickness = (mm)                             200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         1558

Room 4 : 126 Keuken
        Room is modelled as a single zone.
        Room Length (m) =                                  1.80
        Room Width (m) =                                   1.60
        Maximum Room Height (m) =                          2.60
        Minimum Room Height (m) =                          2.60
        Floor Elevation (m) =                              3.000
        Absolute X Position (m) =                          16.200
        Absolute Y Position (m) =                          4.270
        Room 4 has a flat ceiling.
        Shape Factor (Af/H^2) =                            0.4

        Wall Surface is brick
        Wall Density (kg/m3) =                             1600.0
        Wall Conductivity (W/m.K) =                        0.690
        Wall Specific Heat (J/kg.K) =                      840
        Wall Emissivity =                                  0.88
        Wall Thickness (mm) =                              200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =         963

        Ceiling Surface is concrete
        Ceiling Density (kg/m3) =                          2300.0
```

```
         Ceiling Conductivity (W/m.K) =                  1.200
         Ceiling Specific Heat (J/kg.K) =                880
         Ceiling Emissivity =                            0.50
         Ceiling Thickness (mm) =                        200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      1558

         Floor Surface is concrete
         Floor Density (kg/m3) =                         2300.0
         Floor Conductivity (W/m.K) =                    1.200
         Floor Specific Heat (J/kg.K) =                  880
         Floor Emissivity =                              0.50
         Floor Thickness = (mm)                          200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      1558

Room 5 : 129.1 Corridor
         Room Length (m) =                               19.00
         Room Width (m) =                                1.70
         Maximum Room Height (m) =                       2.60
         Minimum Room Height (m) =                       2.60
         Floor Elevation (m) =                           3.000
         Absolute X Position (m) =                       3.600
         Absolute Y Position (m) =                       5.870
         Room 5 has a flat ceiling.
         Shape Factor (Af/H^2) =                         4.8

         Wall Surface is brick
         Wall Density (kg/m3) =                          1600.0
         Wall Conductivity (W/m.K) =                     0.690
         Wall Specific Heat (J/kg.K) =                   840
         Wall Emissivity =                               0.88
         Wall Thickness (mm) =                           200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      963

         Ceiling Surface is concrete
         Ceiling Density (kg/m3) =                       2300.0
         Ceiling Conductivity (W/m.K) =                  1.200
         Ceiling Specific Heat (J/kg.K) =                880
         Ceiling Emissivity =                            0.50
         Ceiling Thickness (mm) =                        200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      1558

         Floor Surface is concrete
         Floor Density (kg/m3) =                         2300.0
         Floor Conductivity (W/m.K) =                    1.200
         Floor Specific Heat (J/kg.K) =                  880
         Floor Emissivity =                              0.50
         Floor Thickness = (mm)                          200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      1558

Room 6 : Schacht 9
         Room is modelled as a single zone.
         Room Length (m) =                               0.60
         Room Width (m) =                                0.60
         Maximum Room Height (m) =                       9.40
         Minimum Room Height (m) =                       9.40
         Floor Elevation (m) =                           2.200
         Absolute X Position (m) =                       15.600
         Absolute Y Position (m) =                       7.570
         Room 6 has a flat ceiling.
         Shape Factor (Af/H^2) =                         0.0

         Wall Surface is brick
         Wall Density (kg/m3) =                          1600.0
         Wall Conductivity (W/m.K) =                     0.690
         Wall Specific Heat (J/kg.K) =                   840
         Wall Emissivity =                               0.88
         Wall Thickness (mm) =                           200.0
         SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =      963

         Ceiling Surface is concrete
         Ceiling Density (kg/m3) =                       2300.0
         Ceiling Conductivity (W/m.K) =                  1.200
         Ceiling Specific Heat (J/kg.K) =                880
```

```
        Ceiling Emissivity =                              0.50
        Ceiling Thickness (mm) =                          200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =        1558

        Floor Surface is concrete
        Floor Density (kg/m3) =                           2300.0
        Floor Conductivity (W/m.K) =                      1.200
        Floor Specific Heat (J/kg.K) =                    880
        Floor Emissivity =                                0.50
        Floor Thickness = (mm)                            200.0
        SQROOT Thermal Inertia (J.m-2.s-1/2.K-1) =        1558

====================================================================
Wall Vents
====================================================================
Vent   1 : 119 Woonkamer-balkon
                   From room 1 to 7
                   Rear  face of room 1
                   Offset (m) =                           1.800
                   Vent Width (m) =                       0.001
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   2 : 119 Woonkamer-keuken
                   From room 1 to 2
                   Front face of room 1
                   Offset (m) =                           1.800
                   Vent Width (m) =                       1.800
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   3 : 119 Keuken-gang-deur
                   From room 2 to 5
                   Front face of room 2
                   Offset (m) =                           0.050
                   Vent Width (m) =                       0.800
                   Vent Height (m) =                      2.100
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.100
                   Opening Time (sec) =                   300
                   Closing Time (sec) =                   1200
                   Discharge Coefficient (-) =            0.680

Vent   4 : 126 Woonkamer-balkon
                   From room 3 to 7
                   Front face of room 3
                   Offset (m) =                           1.800
                   Vent Width (m) =                       0.001
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   5 : 126 Woonkamer-keuken
                   From room 3 to 4
                   Rear  face of room 3
                   Offset (m) =                           1.800
                   Vent Width (m) =                       1.800
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
```

```
                   Discharge Coefficient (-) =            1.000

Vent   6 : 126 Keuken-gang
                   From room 4 to 5
                   Rear  face of room 4
                   Offset (m) =                           0.900
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   7 : 129 Gang-trap-deur
                   From room 5 to 7
                   Right  face of room 5
                   Offset (m) =                           0.800
                   Vent Width (m) =                       0.900
                   Vent Height (m) =                      2.100
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.100
                   Opening Time (sec) =                   320
                   Closing Time (sec) =                   330
                   Discharge Coefficient (-) =            0.680

Vent   8 : 129 Gang-trap-links
                   From room 5 to 7
                   Left  face of room 5
                   Offset (m) =                           0.800
                   Vent Width (m) =                       0.008
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   9 : 119 Keuken-gang
                   From room 2 to 5
                   Front face of room 2
                   Offset (m) =                           0.900
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent   10 : 019 Keuken-schacht 9
                   From room 6 to 7
                   Right  face of room 6
                   Offset (m) =                           0.250
                   Vent Width (m) =                       0.100
                   Vent Height (m) =                      0.100
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               0.100
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            0.680

Vent   11 : 119 Keuken-schacht 9
                   From room 2 to 6
                   Left  face of room 2
                   Offset (m) =                           0.250
                   Vent Width (m) =                       0.100
                   Vent Height (m) =                      0.100
                   Vent Sill Height (m) =                 2.000
                   Vent Soffit Height (m) =               2.100
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            0.680
```

```
Vent  12 : 219 Keuken-schacht 9
                  From room 6 to 7
                  Right  face of room 6
                  Offset (m) =                            0.250
                  Vent Width (m) =                        0.100
                  Vent Height (m) =                       0.100
                  Vent Sill Height (m) =                  5.600
                  Vent Soffit Height (m) =                5.700
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             0.680

Vent  13 : 129 Gang-trap-rechts
                  From room 5 to 7
                  Right  face of room 5
                  Offset (m) =                            0.500
                  Vent Width (m) =                        0.008
                  Vent Height (m) =                       2.600
                  Vent Sill Height (m) =                  0.000
                  Vent Soffit Height (m) =                2.600
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             1.000

Vent  14 : 123 Keuken-gang
                  From room 5 to 7
                  Front face of room 5
                  Offset (m) =                            2.700
                  Vent Width (m) =                        0.005
                  Vent Height (m) =                       2.600
                  Vent Sill Height (m) =                  0.000
                  Vent Soffit Height (m) =                2.600
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             1.000

Vent  15 : 319 Keuken-schacht 9
                  From room 6 to 7
                  Right  face of room 6
                  Offset (m) =                            0.250
                  Vent Width (m) =                        0.100
                  Vent Height (m) =                       0.100
                  Vent Sill Height (m) =                  8.200
                  Vent Soffit Height (m) =                8.300
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             0.680

Vent  16 : 124 Keuken-gang
                  From room 5 to 7
                  Front face of room 5
                  Offset (m) =                            6.300
                  Vent Width (m) =                        0.005
                  Vent Height (m) =                       2.600
                  Vent Sill Height (m) =                  0.000
                  Vent Soffit Height (m) =                2.600
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             1.000

Vent  17 : 125 Keuken-gang
                  From room 5 to 7
                  Front face of room 5
                  Offset (m) =                            9.900
                  Vent Width (m) =                        0.005
                  Vent Height (m) =                       2.600
                  Vent Sill Height (m) =                  0.000
                  Vent Soffit Height (m) =                2.600
                  Opening Time (sec) =                    0
                  Closing Time (sec) =                    0
                  Discharge Coefficient (-) =             1.000
```

```
Vent  18 : 128 Keuken-gang
                   From room 5 to 7
                   Front face of room 5
                   Offset (m) =                           17.100
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent  19 : 122 Keuken-gang
                   From room 5 to 7
                   Rear  face of room 5
                   Offset (m) =                           2.700
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent  20 : 121 Keuken-gang
                   From room 5 to 7
                   Rear  face of room 5
                   Offset (m) =                           6.300
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent  21 : 120 Keuken-gang
                   From room 5 to 7
                   Rear  face of room 5
                   Offset (m) =                           9.900
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

Vent  22 : 118 Keuken-gang
                   From room 5 to 7
                   Rear  face of room 5
                   Offset (m) =                           17.100
                   Vent Width (m) =                       0.005
                   Vent Height (m) =                      2.600
                   Vent Sill Height (m) =                 0.000
                   Vent Soffit Height (m) =               2.600
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   0
                   Discharge Coefficient (-) =            1.000

====================================================================
Ceiling/Floor Vents
====================================================================
Vent ID 1
Upper room 13 to lower room 12
                   Vent Area (m2) =                       0.096
                   Opening Time (sec) =                   0
                   Closing Time (sec) =                   600
                   Discharge Coefficient (-) =            1
                   Open method =                          Manual

Vent ID 2
Upper room outside to lower room 6
```

```
                   Vent Area (m2) =                        0.096
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0
                   Discharge Coefficient (-) =             0.6
                   Open method =                           Manual

Vent ID 3
Upper room outside to lower room 6
                   Vent Area (m2) =                        0.096
                   Opening Time (sec) =                    0
                   Closing Time (sec) =                    0
                   Discharge Coefficient (-) =             0.6
                   Open method =                           Manual

====================================================================
Ambient Conditions
====================================================================
Interior Temp (C) =                                        27.0
Exterior Temp (C) =                                        27.0
Relative Humidity (%) =                                    70

====================================================================
Tenability Parameters
====================================================================
Monitoring Height for Visibility and FED (m) =             2.00
Asphyxiant gas model =                                     FED(CO/HCN)
Occupant Activity Level =                                  Light
Visibility calculations assume:                            reflective signs
Egress path segments for FED calculations
1. Start Time (sec)                                        0
1. End Time (sec)                                          600
1. Room                                                    1
2. Start Time (sec)                                        0
2. End Time (sec)                                          0
2. Room                                                    0
3. Start Time (sec)                                        0
3. End Time (sec)                                          0
3. Room                                                    0

====================================================================
Sprinkler / Detector Parameters
====================================================================
         Ceiling Jet model used is NIST JET.
         Sprinkler System Reliability                      1.000
         Sprinkler Probability of Suppression              0.000
         Sprinkler Cooling Coefficient                     1.000

====================================================================
Smoke Detector Parameters
====================================================================
         Smoke Detection System Reliability                1.000


====================================================================
Mechanical Ventilation (to/from outside)
====================================================================
Mechanical Ventilation not installed.
         Mech ventilation system reliability               1.000


====================================================================
Description of the Fire
====================================================================
CO Yield pre-flashover(g/g) =                              0.050
CO Yield post-flashover(g/g) =                             0.200
Soot Yield pre-flashover(g/g) =                            0.160
Soot Yield post-flashover(g/g) =                           0.250
Flame Emission Coefficient (1/m) =                         1.00
Fuel - Carbon Moles                                        1.00
Fuel - Hydrogen Moles                                      2.00
Fuel - Oxygen Moles                                        0.50
Fuel - Nitrogen Moles                                      0.00
Stoichiometric air/fuel ratio                              9.5
```

```
Burning objects are manually positioned in room.
Enhanced burning submodel is                          OFF

Burning Object No 1
bank
              Located in Room                         1
              Energy Yield (kJ/g) =                   24.4
              CO2 Yield (kg/kg fuel) =                1.690
              H2O Yield (kg/kg fuel) =                0.818
              Heat Release Rate Per Unit Area (kW/m2) = 500.0
              Radiant Loss Fraction =                 0.30
              Fire Elevation (m) =                    0.450
              Fire Object Length (m) =                2.030
              Fire Object Width (m) =                 0.970
              Fire Object Height (m) =                0.810
              Location, X-coordinate (m) =            0.200
              Location, Y-coordinate (m) =            0.200
              Fire Location (for entrainment) =       CENTRE
              Plume behaviour is                      UNDISTURBED

              Time (sec)               Heat Release (kW)
               0                       0
               50                      5
               100                     10
               150                     10
               200                     278
               250                     318
               300                     350
               350                     613
               400                     715
               450                     1199
               500                     1289
               550                     1000
               600                     813
               650                     780
               700                     283
               750                     162
               1200                    20
```

6. Case study baseline model (CFAST)

Release Version : CFAST 7.4.2

OVERVIEW

Compartments	Doors, ...	Ceil. Vents, ...	MV Connects
29	50	3	8

Simulation Time (s)	Output Interval (s)	Smokeview Interval (s)	Spreadsheet Interval (s)
1200.00	60.00	1.00	1.00

AMBIENT CONDITIONS

Interior Temperature (C)	Interior Pressure (Pa)	Exterior Temperature (C)	Exterior Pressure (Pa)
20.	101299.	20.	101299.

COMPARTMENTS

Compartment Name	Width (m)	Depth (m)	Height (m)	Floor (m)	Ceiling Height (m)
8 Schacht					
9 Schacht					
10 Schacht					
118 WK	3.60	4.27	2.60	3.00	5.60
118 KK	1.80	1.60	2.60	3.00	5.60
119 WK	3.60	4.27	2.60	3.00	5.60
119 KK	1.80	1.60	2.60	3.00	5.60
120 WK	3.60	4.27	2.60	3.00	5.60
120 KK	1.80	1.60	2.60	3.00	5.60
125 WK	3.60	4.27	2.60	3.00	5.60
125 KK	1.80	1.60	2.60	3.00	5.60
126 WK	3.60	4.27	2.60	3.00	5.60
126 KK	1.80	1.60	2.60	3.00	5.60
128 WK	3.60	4.27	2.60	3.00	5.60
128 KK	1.80	1.60	2.60	3.00	5.60
129 Cor	19.00	1.70	2.60	3.00	5.60
218 KK	1.80	1.60	2.60	5.80	8.40
218 WK	3.60	4.27	2.60	5.80	8.40
219 WK	3.60	4.27	2.60	5.80	8.40
219 KK	1.80	1.60	2.60	5.80	8.40
220 WK	3.60	4.27	2.60	5.80	8.40
220 KK	1.80	1.60	2.60	5.80	8.40
225 WK	3.60	4.27	2.60	5.80	8.40
225 KK	1.80	1.60	2.60	5.80	8.40
226 WK	3.60	4.27	2.60	5.80	8.40
226 KK	1.80	1.60	2.60	5.80	8.40
228 WK	3.60	4.27	2.60	5.80	8.40
228 KK	1.80	1.60	2.60	5.80	8.40
229 Cor	19.00	1.70	2.60	5.80	8.40

VENT CONNECTIONS

Wall Vents (Doors, Windows, ...)

From Compartment	To Compartment	Vent Number	Width (m)	Sill Height (m)	Soffit Height (m)	
118 WK	Outside	1	0.00	0.00	2.60	
119 WK	Outside	2	0.00	0.00	2.60	
120 WK	Outside	3	0.00	0.00	2.60	
125 WK	Outside	4	0.00	0.00	2.60	
126 WK	Outside	5	0.00	0.00	2.60	
128 WK	Outside	6	0.00	0.00	2.60	
218 WK	Outside	7	0.00	0.00	2.60	
219 WK	Outside	8	0.00	0.00	2.60	
220 WK	Outside	9	0.00	0.00	2.60	
225 WK	Outside	10	0.00	0.00	2.60	
226 WK	Outside	11	0.00	0.00	2.60	
228 WK	Outside	12	0.00	0.00	2.60	
118 WK	118 KK	13	1.80	0.00	2.60	
119 WK	119 KK	14	1.80	0.00	2.60	
120 WK	120 KK	15	1.80	0.00	2.60	
125 WK	125 KK	16	1.80	0.00	2.60	
126 WK	126 KK	17	1.80	0.00	2.60	
128 WK	128 KK	18	1.80	0.00	2.60	
218 WK	218 KK	19	1.80	0.00	2.60	
219 WK	219 KK	20	1.80	0.00	2.60	
220 WK	220 KK	21	1.80	0.00	2.60	
225 WK	225 KK	22	1.80	0.00	2.60	
226 WK	226 KK	23	1.80	0.00	2.60	
228 WK	228 KK	24	1.80	0.00	2.60	
118 KK	129 Cor	25	0.00	0.00	2.60	
119 KK	129 Cor	26	0.00	0.00	2.60	
120 KK	129 Cor	27	0.00	0.00	2.60	
129 Cor	Outside	28	0.00	0.00	2.60	
129 Cor	Outside	29	0.00	0.00	2.60	
129 Cor	Outside	30	0.00	0.00	2.60	
129 Cor	Outside	31	0.00	0.00	2.60	
125 KK	129 Cor	32	0.00	0.00	2.60	
126 KK	129 Cor	33	0.00	0.00	2.60	
128 KK	129 Cor	34	0.00	0.00	2.60	
218 KK	229 Cor	35	0.00	0.00	2.60	
219 KK	229 Cor	36	0.00	0.00	2.60	
220 KK	229 Cor	37	0.00	0.00	2.60	
229 Cor	Outside	38	0.00	0.00	2.60	
229 Cor	Outside	39	0.00	0.00	2.60	
229 Cor	Outside	40	0.00	0.00	2.60	
229 Cor	Outside	41	0.00	0.00	2.60	
225 KK	229 Cor	42	0.00	0.00	2.60	
226 KK	229 Cor	43	0.00	0.00	2.60	
228 KK	229 Cor	44	0.00	0.00	2.60	
129 Cor	Outside	45	0.00	0.00	2.60	
129 Cor	Outside	46	0.00	0.00	2.60	
229 Cor	Outside	47	0.00	0.00	2.60	
229 Cor	Outside	48	0.00	0.00	2.60	
129 Cor	Outside	49	0.90	0.00	2.10	Ramp #1
119 KK	129 Cor	50	0.80	0.00	2.10	Ramp #2

Ceiling and Floor Vents

Top Compartment	Bottom Compartment	Vent Number	Shape	Area (m^2)
Outside	8 Schacht	1	Round	0.10
Outside	9 Schacht	2	Round	0.10
Outside	10 Schacht	3	Round	0.10

Mechanical Vents (Fans)

From Compartment	To Compartment	Fan Number	Area (m^2)	Flowrate (m^3/s)	Trigger	Value (C/W/m^2)
118 KK	8 Schacht	1	0.00	0.02	Temp	72.00
Outside	118 WK	2	0.00	0.02	Temp	72.00
119 KK	9 Schacht	3	0.00	0.02	Temp	72.00
Outside	119 WK	4	0.00	0.02	Temp	72.00
120 KK	10 Schacht	5	0.00	0.02	Temp	72.00
Outside	120 WK	6	0.00	0.02	Temp	72.00
Outside	129 Cor	7	0.00	0.02	Temp	72.00
129 Cor	Outside	8	0.00	0.02	Temp	72.00

VENT RAMPS

From Compartment	To Compartment	Vent Number		(s)	(s)	(s)	(s)	(s)
129 Cor	Outside	49	Time	0	319	320	330	331
119 KK	129 Cor	50	Time	0	299	300	320	321
8 Schacht		1	Time	0	1200			
9 Schacht		1	Time	0	1200			
10 Schacht		1	Time	0	1200			

THERMAL PROPERTIES

Compartment	Ceiling	Wall	Floor
8 Schacht	CON	CON	CON
9 Schacht	CON	CON	CON
10 Schacht	CON	CON	CON
118 WK	CON	NM 2	CON
118 KK	CON	NM 2	CON
119 WK	CON	NM 2	CON
119 KK	CON	NM 2	CON
120 WK	CON	NM 2	CON
120 KK	CON	NM 2	CON
125 WK	CON	NM 2	CON
125 KK	CON	NM 2	CON
126 WK	CON	NM 2	CON
126 KK	CON	NM 2	CON
128 WK	CON	NM 2	CON
128 KK	CON	NM 2	CON
129 COR	CON	NM 2	CON
218 WK	CON	NM 2	CON
218 KK	CON	NM 2	CON
219 WK	CON	NM 2	CON
219 KK	CON	NM 2	CON
220 WK	CON	NM 2	CON
220 KK	CON	NM 2	CON
225 WK	CON	NM 2	CON

225 KK	CON	NM 2	CON
226 WK	CON	NM 2	CON
226 KK	CON	NM 2	CON
228 WK	CON	NM 2	CON

Name	Conductivity	Specific Heat	Density	Thickness	Emissivity
NM 2	0.800	840.	2.100E+03	0.200	0.900
CONCRETE	1.75	1.000E+03	2.200E+03	0.200	0.940
DEFAULT	0.120	00.	800.	1.200E-02	0.900

FIRES

Compartment	Fire Type	Position (x,y,z)	Relative Humidity	Lower O2 Limit	Radiative Fraction
119 WK	Constrained	1.80,2.13,0.45	50.0	10.00	0.30

Chemical formula of the fuel

Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
9.000	16.000	3.000	1.400	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	2.18E+07	0.0	0.45	0.10	1.40E-02	0.20	0.0	0.0
50.	2.29E-04	2.18E+07	5.00E+03	0.45	0.10	1.40E-02	0.20	0.0	0.0
100.	4.59E-04	2.18E+07	1.00E+04	0.45	0.10	1.40E-02	0.20	0.0	0.0
150.	4.59E-04	2.18E+07	1.00E+04	0.45	0.10	1.40E-02	0.20	0.0	0.0
200.	1.28E-02	2.18E+07	2.78E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
250.	1.46E-02	2.18E+07	3.18E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
300.	1.61E-02	2.18E+07	3.50E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
350.	2.81E-02	2.18E+07	6.13E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
370.	3.28E-02	2.18E+07	7.15E+05	0.45	0.10	1.40E-02	0.20	0.0	0.0
400.	5.50E-02	2.18E+07	1.20E+06	0.45	0.10	1.40E-02	0.20	0.0	0.0
450.	5.91E-02	2.18E+07	1.29E+06	0.45	0.10	1.40E-02	0.20	0.0	0.0
500.	4.59E-02	2.18E+07	1.00E+06	0.45	0.21	5.10E-02	0.20	0.0	0.0
550.	3.73E-02	2.18E+07	8.13E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
600.	3.58E-02	2.18E+07	7.80E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
700.	1.30E-02	2.18E+07	2.83E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
750.	7.43E-03	2.18E+07	1.62E+05	0.45	0.21	5.10E-02	0.20	0.0	0.0
1200.	1.83E-03	2.18E+07	4.00E+04	0.45	0.21	5.10E-02	0.20	0.0	0.0

TARGETS

Target	Compartment	Position (x, y, z)	Direction (x, y, z)	Material
Targ 118	118 WK	1.80,2.13,2.60	0.00,0.00,1.00	CON
Targ 119	119 WK	1.80,2.13,2.60	0.00,0.00,1.00	CON
Targ 120	120 WK	1.80,2.13,2.60	0.00,0.00,1.00	CON
Targ 129	129 COR	9.50,0.85,2.60	0.00,0.00,1.00	CON

7. Sensitivity analysis

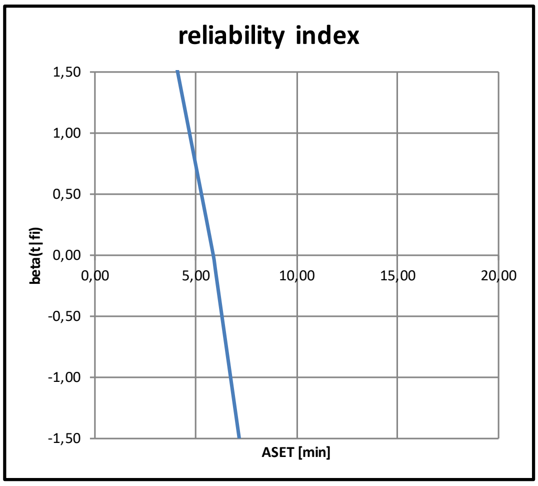
ASET
Case: Schuylenburchy casestudy apartment 1.18
Assessment criterion: Optical density 0.1 1/m

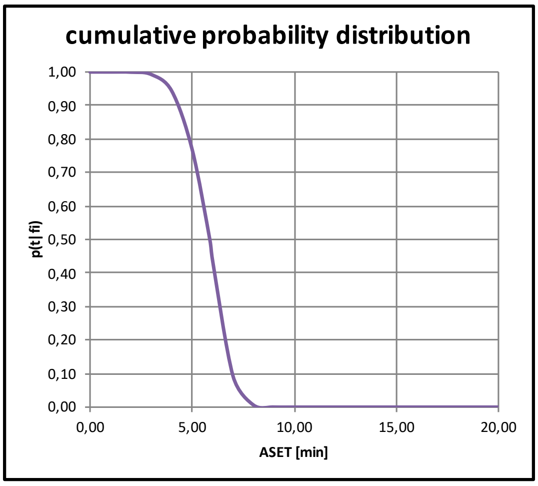
SENSITIVITY ANALYSIS stochastic boundary conditions			
			Average
1	**Hc+**	Heat of combustion	21,8 MJ/kg
2	**Hc-**	Heat of combustion	21,8 MJ/kg
3	**Td-1+**	Time opening door	5,0 min
4	**Td-1-**	Time opening door	5,0 min
5	**Td-2+**	Duration opening door	0,33 min
6	**Td-2-**	Duration opening door	0,33 min
7	**CO+**	CO yield	100 %
8	**CO-**	CO yield	100 %
9	**Soot+**	Soot yield	100 %
10	**Soot-**	Soot yield	100 %
13	**Int. Air+**	Intern airtightness (width	0,15 cm
14	**Int. Air-**	Intern airtightness (width	0,15 cm
15	**Ext. Air+**	Extern airtightness (width	0,09 cm
16	**Ext. Air-**	Extern airtightness (width	0,09 cm
		ASET	5,87 min

Probabilistic: sensitivity analysis				
	variation V	deviation s	value x + dx	ASET [min]
1	0,20	4,36	26,16	5,72
2	-0,20	-4,36	17,44	6,00
3	0,15	0,75	5,75	5,10
4	-0,15	-0,75	4,25	6,23
5	0,20	0,07	0,40	5,77
6	-0,20	-0,07	0,27	6,02
7	0,50	50,00	150,00	5,87
8	-0,50	-50,00	50,00	5,87
9	0,50	50,00	150,00	5,55
10	-0,50	-50,00	50,00	6,83
13	0,50	0,075	0,225	5,75
14	-0,50	-0,075	0,075	6,38
15	0,50	0,045	0,135	5,97
16	-0,50	-0,045	0,045	5,92

standard deviation			
dt/dx	s·dt/dx	$(s \cdot dt/dx)^2$	
-0,03	-0,15	0,02	
-0,03	0,13		0,02
-1,02	-0,77	0,59	
-0,49	0,37		0,13
-1,50	-0,10	0,01	
-2,25	0,15		0,02
0,00	0,00		
0,00	0,00		
-0,01	-0,32	0,10	
-0,02	0,97		0,93
-1,56	-0,12	0,01	
-6,89	0,52		0,27
2,22	0,10		0,01
-1,11	0,05		0,00
variancy(t) =		0,734	1,389
s(t) =		0,857	1,178

reliability and failure probability			
t [min]	s(t)	beta(t|fi)	p(t|fi)
0,00	1,178	4,98	1,00
1,00	1,178	4,13	1,00
2,00	1,178	3,28	1,00
3,00	1,178	2,43	0,99
4,00	1,178	1,58	0,94
5,00	1,178	0,74	0,77
5,87	0,857	0,00	0,50
6,00	0,857	-0,16	0,44
7,00	0,857	-1,32	0,09
8,00	0,857	-2,49	0,01
9,00	0,857	-3,66	0,00
10,00	0,857	-4,82	0,00
20,00	0,857	-16,49	0,00





ASET

Case: Schuylenburchy casestudy corridor 1.29
Assessment criterion: Optical density 0.2 1/m

SENSITIVITY ANALYSIS stochastic boundary conditions				
			Average	
1	**Hc+**	Heat of combustion	21,8	MJ/kg
2	**Hc-**	Heat of combustion	21,8	MJ/kg
3	**Td-1+**	Time opening door	5,0	Min
4	**Td-1-**	Time opening door	5,0	Min
5	**Td-2+**	Duration opening door	0,33	Min
6	**Td-2-**	Duration opening door	0,33	Min
7	**CO+**	CO yield	100	%
8	**CO-**	CO yield	100	%
9	**Soot+**	Soot yield	100	%
10	**Soot-**	Soot yield	100	%
13	**Int. Air+**	Intern airtightness (width	0,15	cm
14	**Int. Air-**	Intern airtightness (width	0,15	cm
15	**Ext. Air+**	Extern airtightness (width	0,09	cm
16	**Ext. Air-**	Extern airtightness (width	0,09	cm
		ASET	2,62	Min

Probabilistic: sensitivity analysis				
	variation v	deviation s	value x + dx	ASET [min]
1	0,20	4,36	26,16	2,62
2	-0,20	-4,36	17,44	2,63
3	0,15	0,75	5,75	2,62
4	-0,15	-0,75	4,25	2,62
5	0,20	0,07	0,40	2,62
6	-0,20	-0,07	0,27	2,62
7	0,50	50,00	150,00	2,62
8	-0,50	-50,00	50,00	2,62
9	0,50	50,00	150,00	2,13
10	-0,50	-50,00	50,00	2,73
13	0,50	0,075	0,225	2,62
14	-0,50	-0,075	0,075	2,63
15	0,50	0,045	0,135	2,63
16	-0,50	-0,045	0,045	2,62

standard deviation			
dt/dx	s·dt/dx	$(s \cdot dt/dx)^2$	
0,00	0,00		
0,00	0,02		0,00
0,00	0,00		
0,00	0,00		
0,00	0,00		
0,00	0,00		
0,00	0,00		
0,00	0,00		
-0,01	-0,48	0,23	
0,00	0,12		0,01
0,00	0,00		
-0,22	0,02		0,00
0,37	0,02		0,00
0,00	0,00		
variancy(t) =		0,234	0,014
s(t) =		0,483	0,120

reliability and failure probability			
t [min]	s(t)	beta(t|fi)	p(t|fi)
0,25	0,120	19,69	1,00
2,00	0,120	5,13	1,00
2,50	0,120	0,97	0,83
2,62	0,483	-0,01	0,50
3,00	0,483	-0,79	0,21
5,00	0,483	-4,93	0,00
6,00	0,483	-7,00	0,00
7,00	0,483	-9,07	0,00
8,00	0,483	-11,14	0,00
9,00	0,483	-13,21	0,00
10,00	0,483	-15,28	0,00
20,00	0,483	-35,97	0,00