Fire Safety Engineering at TU/e

a 10-year overview of the Fellowship FSE

1. Introduction and goals

The chairman of NL-Ingenieurs, drs. E.T.H.M. Nijpels, expressed in a letter at the Board of Directors on September 14th 2010 his concerns about the lack of a chair at the Dutch universities in the field of fire safety.
The unit Building Physics and Services (BPS) highlighted the importance of fire safety during a number of lectures with guest lecturers. As a result of the letter of NL-Ingenieurs, Wim Zeiler (TU/e) and Harry Nieman (Nieman Consultants) started discussions to establish Fire Safety Engineering more strongly in the Master programs. Ruud van Herpen was found willing to provide a number of lectures as Fellow and to supervise the Master Projects on this topic. Sponsors were sought to fund the Fellowship and they united in the Foundation Fellowship FSE WO[2]. The TU/e responded by appointing Ruud van Herpen as Fellow Fire Safety Engineering (FSE) at the unit Building Physics and Services (BPS) of the Department Built Environment. That does not mean that the fellowship FSE only is involved in fire safety related to building physics and services. Other expertises in the Department Built Environment are important too in fire safety. Expertises like façades, building constructions, construction materials and simulation techniques.

Therefore the following goals are formulated for the fellow FSE:

- Providing a mastercourse FSE, guest lectures in other courses, supporting bachelor- and masterprojects of students, promotional activities to expose FSE at the TU/e.
- Coordination with different areas of expertise within the Department of the Built Environment and setting up a committee of interested parties (companies, knowledge institutes and government).
- Formulating a socially relevant research track within the domain of FSE.

The master track with specialization Fire Safety Engineering at the TU/e is distinctive in comparison with existing master tracks in FSE (Ghent -B, Edinburgh - UK, Lund - S) by the following implementation:

- Performance-based projectspecific approach for tailormade fire safety (comprehensive package of measures for building components, building services and internal organisation), to anticipate on changing boundary conditions due to ageing building population and energy transition in the built environment.
- Quantification of public objectives in acceptable failure risks.
- Formulation and quantification of private objectives like fire resilience, sustainability/durability, protection of property, process and environment.
- Use of preventive 'Lines of Defence' for suppression by the fire service, to connect the links 'prevention' and 'suppression' in the fire safety chain (cooperation of TU/e with the Dutch Fire Service Academy).

Prevention and suppression: important links in the fire safety chain

2. FSE Master research 2013-2023

This chapter provides an overview of all master research projects and graduation projects of students. Master research projects have a study load of 10 ECT, graduation projects at least 45 ECT. Abstracts of the graduation projects are given in chapter 3.

Overview of student master research projects within the unit BPS in FSE:

- Eef Brouns (2013) – Investigation of suppression techniques in containerbuilding TRONED;
- Annelous Bossers, Thijs van Druenen (2014) – Zonemodels and natural ventilation through openings in separation walls;
- Marthe Doornbos (2015) – Fire safety in pavilion Summerlabb: AST vs. RST;
- Dolf van Onna (2015) – Residential fire expoeriments in Zutphen: Modelling and validation in CFAST;
- Babette Mattheüs (2016) – Firesafe buildings without escaperoutes;
- Reem Shakerchi (2016) – Comparison of evacuation model FDS-Evac with ‘Rekenhulp Bouwbesluit 2012’ (building code assessment method);
- Nick Tenbült (2017) – Impact of the mechanical ventilation system on fire behavior in airtight dwellings;
- Erwin Slotboom (2017) – Efficiency of hot smoke layer cooling techniques: investigation of an experimental setup;
- Lara Quaas (2018) – Reliability of fire compartmentation;
- Bram Dorsman (2019) – Probabilistic approach of ASET and RSET for bedridden building occupants;
- Jesse Hamers (2020) – Traveling fire concept in parking garages: consequences for the load bearing steel structure;

- Joost Dumas (2022) – Stay-in-place concept for a multi-storey multi-compartment building;
- Nora Kuiper (2022) – Assessing the risk of flanking of thermally light facades in case of fire;
- Tessa Junggeburth (2022) – Fire risk of building integrated photovoltaics in façades;
- Serena Siciliano (2024) – Fire risk of green façades.

Overview of master graduation projects within the unit BPS in FSE:

- Ronald Huizinga (TU/e, 2012) – Influence of the performance of triple and double glazing on the fire development in a dwelling; *Nominated IFV-VVBA Thesis award 2013*
- Niels Starting (TU/e, 2012) – Evacuation of bedridden building occupants; *Nominated IFV-VVBA Thesis award 2013*
- Rob Kisjes (TU/e, 2014) – Brandveiligheid in hoogbouw: doelkwantificering op basis van Bouwbesluit 2012;
- Yan-Ying Wong (TUD-C.E., 2014) – Steel structures in an open carpark: the influence of trapped smoke on the fire resistance of steel beams;
- Luuk de Kluiver (TU/e, 2014) – Establishing flammability ranges of building insulation materials;
- Sander Giunta d'Albani (TU/e, 2014) – Fire behavior of sandwich panel core materials in the pre flashover phase; *Winner IFV-VVBA Thesis award 2015*
- Vincent van den Brink (TU/e, 2015) – Fire safety and suppression in modern residential buildings; *Nominated IFV-VVBA Thesis award 2015*
- Jelmer Feenstra (TU/e, 2016) – Two-way coupling of CFD fire simulations and FE modelling on thin walled steel structures; *Winner IFV-VVBA Thesis award 2016*

- Babette Mattheus (TU/e, 2017) – Fire propagation in an open carpark;
- Reem Shakerchi (TU/e, 2017) – Numerical simulation of external flames in ventilation controlled post flashover fires;
- Nick Tenbült (TU/e, 2018) – Cooling of a hot smoke layer by a sprinkler spray; *Winner IFV-VVBA Thesis award 2018;*
- Jan de Boer (TU/e, 2018) – Automated two-way coupled CFD fire and thermomechanical FE analysis of a self-supporting sandwich panel facadesystem;
- Lennart Gerritsen (TU/e, 2018) – Fire safety risk checker: risk factors for residential housing for elderly;
- Maarten Arntz (TU/e, 2018) – The bearing capacity of an aluminium curtain wall, exposed to a standard fire;
- Mike van der Linden (TU/e, 2019) – Fire safety and the ageing population: a probabilistic link of preventive and repressive measures in residential buildings;
- Marc Scholman (TU/e, 2020) – Different concepts for personal safety in a multi-storey residential building, related to internal smoke propagation;
- Sue Ellen de Nijs (TU/e, 2021) - Thermomechanical modeling of composite slab joints under fire; *Nominated IFV-VVBA Thesis award 2022*
- Andrès Berdugo Calderon (PT Torino, 2022) – Fire resilience of cross laminated timber constructions in residential buildings;
- Joost Dumas (TU/e, 2023) – Quantitative assessment for fire safety of supertall residential buildings with a probabilistic analysis;
- Nora Kuiper (TU/e, 2023) – Multi-storey residential buildings in the event of fire: relief of the fire-induced overpressure without causing smoke spread via the ventilation system.

3. Master graduation projects

Small fire experiment
in an airtight room

Small CLT
compartment fire test

Furnace for testing
combustible insulation
material in
temperature range 20
– 400 °C

Fellow speech March 2013

Yearly expert class
'FSE – Next Generation'
(2018)

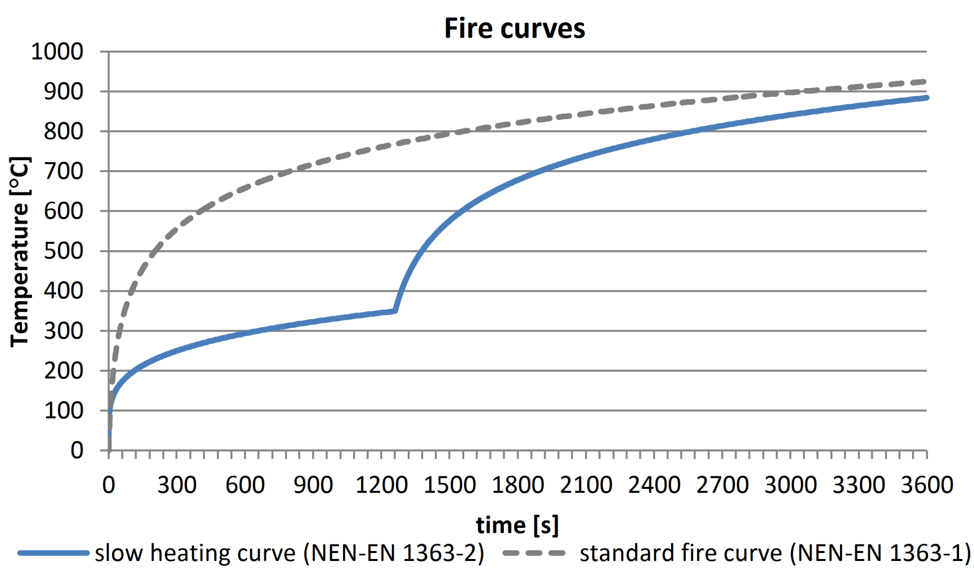
The following sections contain the abstracts of the Master Projects. A number of them were nominated for the IFV-VVBA Thesis Award and some of them won that award.

Influence of the performance of triple and double glazing on the fire development in a dwelling

Ronald Huizinga

Nominated IFV-VVBA Thesis Award 2013

The application of double glazing is wide spread in the current housing stock, low-energy dwellings (such as the passive house concept) will lead to the application of triple glazing. Glass fallout is an important factor that influences the fire development during an enclosure fire.



A smouldering fire seems more likely when the glazing system remains intact, while a flaming fire will be more likely in a situation with major glass fallout. A smouldering fire will lead to a higher toxicity hazards for the occupants and an increased risk on a backdraft.

A flaming fire, on the other hand can lead to flash-over conditions. Therefore it is imperative to know which fire scenario will be more likely, in order to anticipate on it with adequate measures. Until today assumptions are made about the performance of triple glazing in relation to glass fallout during fire without any scientific basis. This Master thesis is initiated to obtain an insight in the time before glass fallout of triple and double glazing systems during an enclosure fire in a dwelling.

The following research question is brought up to approach the subject:

‘’*To what extend does the fallout period of triple glass affect the indoor fire conditions in dwellings differently compared to the fallout period of double glazing?*’

The graduation thesis is based on experimental research with the use of a fire furnace and supporting simulations to assess the likelihood of a fire scenario in a dwelling. The two presented experiments consist of a double and triple glazing assembly with four large and four small windows. Individual temperatures of the glass surface, shaded area, and temperature differences were analysed in relation to glass fallout. The analysis of the results revealed a wide spread between temperatures and glass fallout. Engineering correlations, such as the internal energy in gasvolume and the maximum temperature before glass fallout were established to quantify the difference in performance between triple and double glazing. The results show a detectable difference between the performance, and provide an indicative criterion of glass fallout as a result of internal energy in the gasvolume. Additionally a comparison is made between the experimental results and reference literature on the performance of double glass to verify the obtained criterion in relation to a vertical temperature gradient.

The supporting simulations consists firstly of a calibration in order to retrieve the conditions inside the fire furnace during the experiment. The results enable an assessment of the representativeness of the fire experiment compared to a typical enclosure fire. This assessment indicates that the conditions during the experiment might result in a less pronounced radiation level than one would expect during an enclosure fire. However, multiple uncertainties for both the simulation model as the conditions during the experiment make it inaccurate to quantify the difference in radiation.

Figure 9: experimental setup double glazing

Figure 10: experimental setup triple glazing

Subsequently various fire scenarios were defined to obtain an indication of the probability of glass fallout during an enclosure fire. The assessment of various fire situations is related to the experimentally found criterion and takes into account various boundary conditions such as difference in construction, geometry, type of fire, and ventilation inlets. These results have led to new insights on the probability of an altered fire scenario for dwellings with multi-pane glazing.

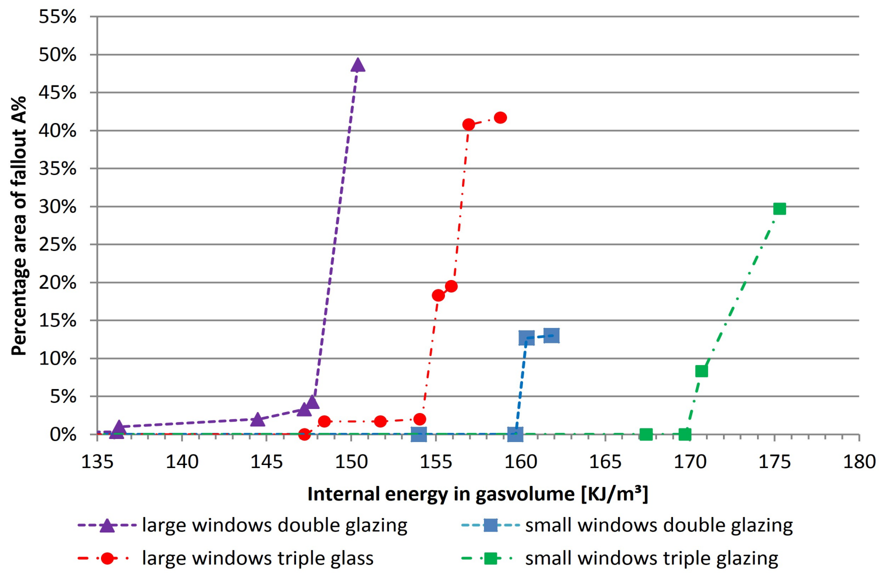


Figure 33: average glass fallout as a function of internal energy in gasvolume inside the fire furnace

One must keep in mind that the given estimation is bound by several limitations. At first only one specific temperature curve is used, which allows only the assessment of the fire scenarios which remain under the given maximum temperature limits as used in the fire furnace. Furthermore, the results only apply for the same compositions and glazing assemblies. Also the experimental study consists of a small sample size, making a statistical approach unreliable. These limitations, combined with the different conditions of the fire furnace compared to an enclosure fire, emphasises a certain nuance on the found criterion.

Evacuation of bedridden building occupants

Niels Strating

Nominated IFV-VVBA Thesis Award 2013

Bedridden building occupants in hospitals and nursing homes who are not able to rescue themselves in case of a fire emergency require assistance during an evacuation. A building emergency team is usually assigned to fulfil this function and will have to remove the occupants from the room. The speed at which such an evacuation is conducted however is not documented and unknown. Assumptions are made when addressing the total evacuation time in hospitals and nursing homes, a theoretical basis on which the statutory regulations in the building code find their basis. Because this particular situation has never been properly investigated, it is also unknown if a safe evacuation of bedridden building occupants can be realized in case of fire.

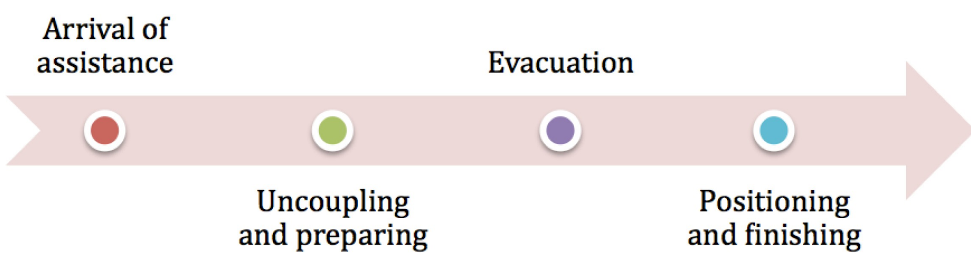
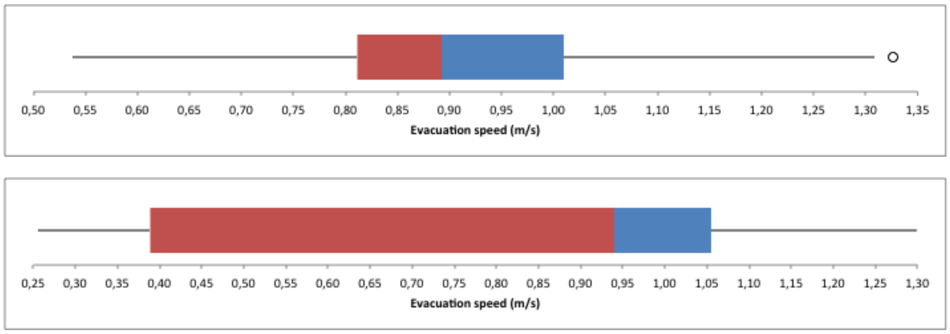
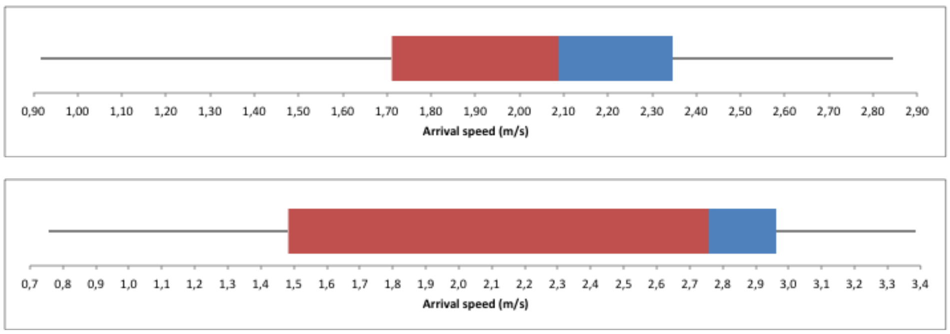


Figure 2.1 – The evacuation scenario.



Evacution speeds in hospitals (upper boxplot, n=91) and nursing homes (lower boxplot, n=14)



Walking speeds in hospitals (upper boxplot, n=91) and nursing homes (lower boxplot, n=14)

An experimental research is conducted in hospitals and nursing homes to obtain insight on the evacuation speed and absolute evacuation times required to judge whether a safe evacuation is possible or not. The results show that 50 percent of the measurements conducted in hospitals lay within a range of 0.81 to 1.01 metres per second, while for nursing homes the results range from 0.40 to 1.05 metres per second. The total evacuation time of one bed in a hospital will require at least 30 seconds when moving the bed outside the fire compartment.
A simulation is furthermore conducted of a hospital and a nursing home, to obtain values on the available safe egress time in both a hospital and a nursing home. Different variants were simulated of the hospital model,

which involve differences in heat release rate and the time constant. Comparing the experimental results with the simulation results indicates that a safe evacuation is strongly dependent on the arrival time of the building emergency team at the room in question and might cause critical situations in both hospitals and nursing homes if the arrival time were to take longer than 3 minutes. In that case, a safe evacuation from the room itself might not be possible.

Furthermore the results show that many of the people who conducted the evacuations were insufficiently trained for this particular situation. The actions they performed during the experiments, e.g. opening doors and not closing them, could result in potentially dangerous situations if a real fire emergency is to occur.

Hospitals	1st Q.	Median	2nd Q.	***Average***
Walking speed to bed [m/s]	1,71	2,09	2,35	***2,04***
Uncoupling bed and infusion [sec]	11,63	13,52	15,47	***14,98***
Evacuation in corridor [m/s]	0,81	0,89	1,01	***0,92***
Passing compartmentdoor and positioning beds [sec]	6,8	7,88	9,07	***8,11***

Nursing homes	1st Q.	Median	2nd Q.	***Average***
Walking speed to bed [m/s]	1,48	2,76	2,96	***2,31***
Uncoupling bed [sec]	5,36	6,43	7,73	***6,92***
Evacuation in corridor [m/s]	0,39	0,94	1,06	***0,81***
Passing compartmentdoor and positioning beds [sec]	3,41	4,25	4,89	***4,2***

Summary of measured evacuation times in hospitals and nursing homes

Fire safety of a highrise office building – a performance based approach

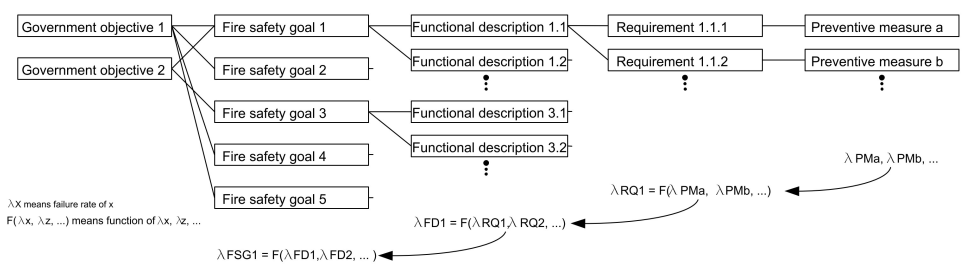
Rob Kisjes

This thesis plans out a fire safety design for a high rise office building based on quantified performances and failure rates. It combines fire safety engineering practices with reliability aspects.
Buildings in the Netherlands have to comply with Dutch legislation, namely the Building decree (Bouwbesluit 2012). This Building decree is rule based and gives prescriptive requirements for buildings up to 70 meters. The Building decree states that for buildings higher than 70 meters an 'equal level of fire safety' should be accomplished. In practice this is reached by applying the non-formalized fire safety guidelines for high rise buildings, published by the SBR (Dutch institute for building and construction branch). But this guidelines have no proved verifiable equal level of fire safety as intended by the Building decree. So it is unclear whether a high rise design meets the legal fire safety level.
In this research a set of fire safety objectives, with quantified performances and failure rates, is derived, based on the fire safety requirements of the Dutch Building decree. This set can serve for a design of a high rise office building, with a verifiable equal level of fire safety as required by the Dutch Building decree. The method is based on the performance based designing with semi-probabilistic approaches which are also used in the Eurocodes. These Eurocodes are also prescribed for building structures in the Building decree and thus have a close relation to the other fire safety aspects. The developed method in this research fits clearly in the 'vision on fire safety' of the Ministry of

Housing for a wider application of performance based designing for larger and complex buildings.

The method to derive the quantified performances and failure probabilities from the Building decree requirements is based on the following aspects:

- The Building decree has a systematic set up, where objectives and goals are broken down in functional descriptions and these functional descriptions are broken down in specific requirements and measures (similar to the method of Systems Engineering). The objectives and goals are specified in qualitative safety terms but misses the failure rate quantifications.
- With the prescribed requirements and preventive measurements the Building decree is representing an implicit reliability. This reliability is the complementary factor of failure. And the failure rates of the preventive measurements can be determined via failure rate databases, life tests or semiprobabilistic calculations.



Based on these two aspects the failure rate of an objective is calculated backwards. And so a complete set of quantified performances and failure rates is worked out for the fire safety objectives. The procedure is outlined in figure below.

With these quantified performances and failure rates for the fire safety objectives, a design is made for a high rise office building. For the 'equal level of fire safety' the general risk formula is used:

Risk = probability (starting of a fire + failing preventive measures) * impact

In a high rise office building the probability of starting a fire is larger than in a smaller office and the impact is larger (more people in the building).

And on the same time the risk (fire safety level) should be the equal to a smaller office. So the probability of failing of preventive measures should be less than in smaller buildings. In fact it should be a factor 10 smaller.

The influence of trapped smoke on the fire resistance of steel beams in an open car park

Yan-Ying Wong (TU Delft)

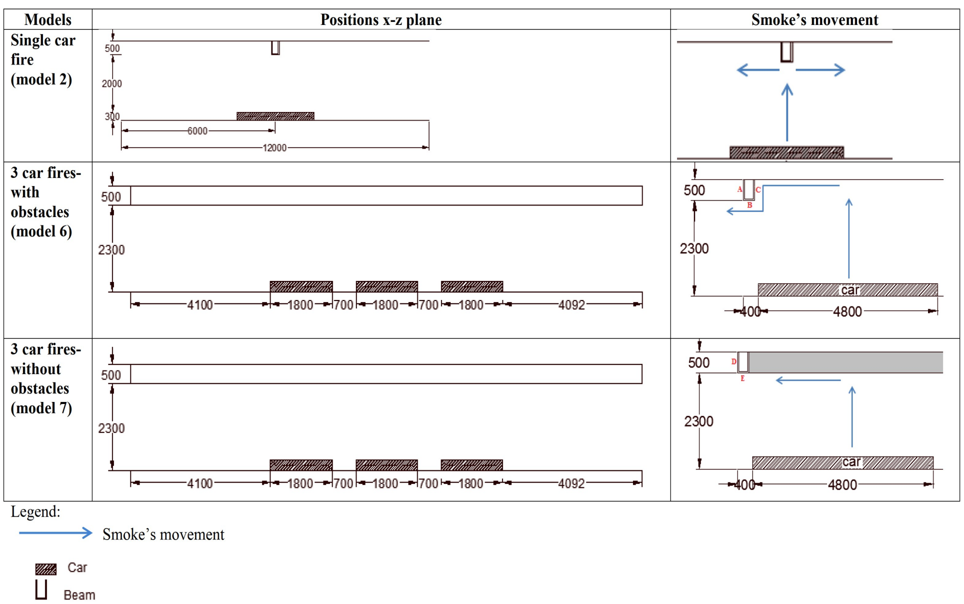
A car in an open car park is on fire. The fire and the smoke unleash a heat that causes the temperature to rise. The open car park is made out of a steel frame and to be designed for a fire resistance of 60 minutes. This car fire is a local fire whereas flashover doesn't occur. The crucial point of the fire is when the steel frame reaches the critical temperature. If this occurs, the steel will fail and might lead to the collapse of the building.
Because it is an open car park, it is assumed the natural ventilation will lead the smoke out of the building very fast. But the smoke can be trapped between the beams, which are present below the ceiling as a support structure for the floor system. The aim is to study whether the influence of trapped smoke between beams in an open car park is significant or not. And is it necessary to take the smoke into account during the design of an open car park when making use of the Bouwen met Staal guideline (BmS- guide), a guideline for the design of the fire safety of an open car park?

In this study the influence of the smoke on the steel structure of the open car park was investigated by making use of a spreadsheet Car Park Fire (CaPaFi) and the software, Fire Dynamic Simulator (FDS). CaPaFi is a spreadsheet which calculates the steel temperatures without taking smoke into account. It is based on real car fire tests and the Eurocode.

FDS is a program that uses computational fluid dynamic calculations to run a simulation (model) of a car fire in an open car park. It calculates the steel temperature of the steel beams taking the effect of smoke into account. All the information for FDS is written in a script beforehand and run afterwards.

A single car fire and a 3 car fire were modeled and studied. To verify the calculations in FDS with CaPaFi, a single car fire model was put up. Because there were still some differences in the results, 4 more models were set up with small adjustments in the first one to fine tune the model (model 2 to 5). According to the study 95% of the car fires are limited to maximum 3 (fully) burnt cars [1]. So, 3 car fires were also taken into account and the smoke. There were two cases with 3 car fires: one with beam sticking out (model 6 with obstacles) and one with beams hidden in the ceiling (model 7 without obstacles).

Table 19 Comparison model 2, 6 and 7: Positioning beam and the smoke's movement (dimensions are in mm)



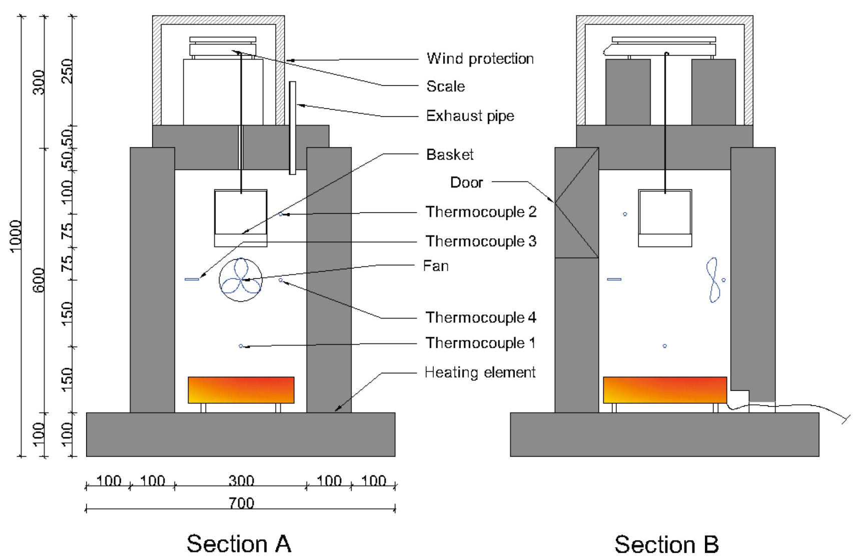
Based on the results of this study, it is found that the smoke which is trapped between the beams can be neglected when making use of the BmS-guide to design the fire safety of an open car park for the steel beams with a height smaller than 500 mm. Also a reasonable explanation could not be found of why the temperatures of the steel beams of FDS are lower than the ones calculated by CaPaFi. And in a 3 car fire model points that are further away from the car fire can be disregarded because their steel temperature calculated by FDS, even though higher than CaPaFi, will never reach the critical temperature. At last, it is still unclear why the increased number of soot doesn't have any effect on the temperature of the steel beams in the single car fire model.

Establishing flammability ranges of building insulation materials

Luuk de Kluiver

This study is focused on insulation materials used as a core for sandwich panels as well as insulation materials used for roofs with a steel deck construction principle. The goal of the study is to experimentally establish flammability limits of the fire effluents resulting from the pyrolysis of insulation materials in order to gain insight in the possibility of a smoke gas explosion during a building fire. For this study 5 different insulation materials were chosen:

- Polyurethane (PUR)
- Polyisocyanurate (PIR)
- Stone wool
- Expanded Polystyrene (EPS)
- Extruded Polystyrene (XPS)

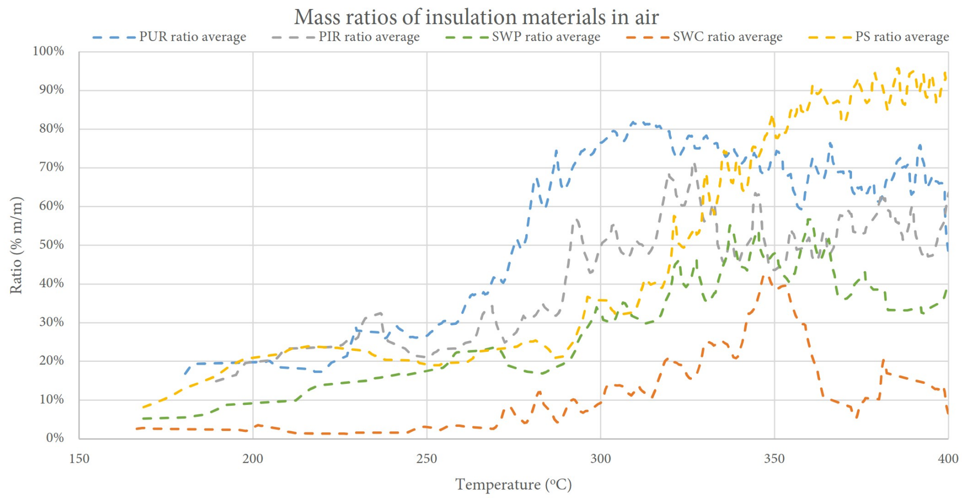


Experimental setup

To establish the required flammability limits an experimental setup was made which is able to measure mass loss in real time. The oven is also able to heat up samples up to 400 °C and measure the temperature in real time. These measurements enabled the calculations of ratios of gas mixtures leaving the oven through an exhaust. The temperature of 400 °C is the limit for testing the materials, because when a compartment on fire reaches 400 °C it is considered as a flashover fire. At this point no firefighters are actively intervening inside the building and a possible smoke gas explosion does not pose a threat anymore.

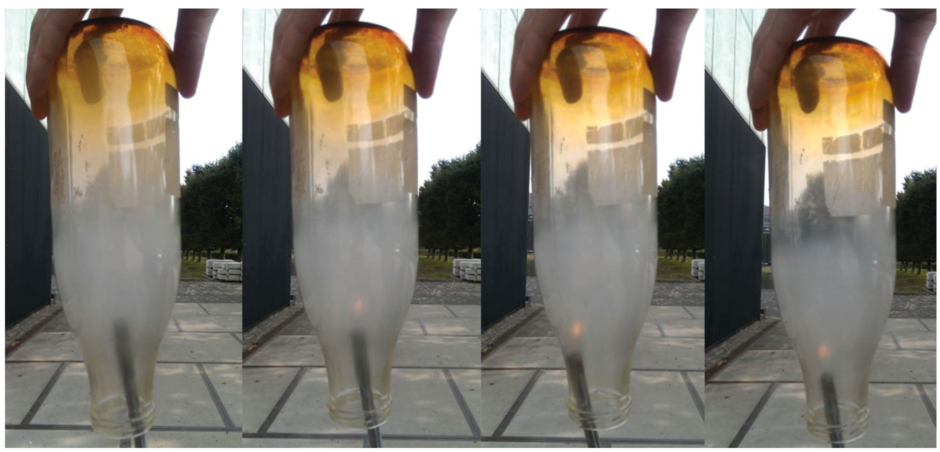
During the experiments conducted in this study, the flammability limits of PIR and Stone wool could not be found. The results also showed that the mass loss of these products during exposure of temperatures below the 400 °C is low compared to PUR, EPS and XPS.

For the material PUR a lower flammability limit as well as an upper flammability limit could be established. The mass loss was high and a broad range of ratios could be detected. The Polystyrene based materials, EPS and XPS, are like PUR and PIR synthetic insulation materials. Unlike PUR and PIR these materials are thermoplastics. This causes the materials to melt before starting pyrolysis. This property resulted in the start of pyrolysis at higher temperatures than the other materials. Once pyrolysis starts, the mass loss rate is high. The highest loss of mass is detected with the materials EPX and XPS. For the Polystyrene based materials a lower flammability limit could be detected. An upper flammability could not be detected. For the materials Stone wool and PIR flammability limits could not be detected.



Mass loss rates of PUR, PIR, Stone wool and EPS

As a final part of this study some modelling was done for typical buildings with a steel deck roof structure, from this modelling was derived that in none of the cases a smoke gas explosion could occur resulting from the pyrolysis of building insulation materials alone. However the mass of the pyrolysis gas from the insulation materials are of such a level available in the smoke layer that the chance of a smoke gas explosion increases.



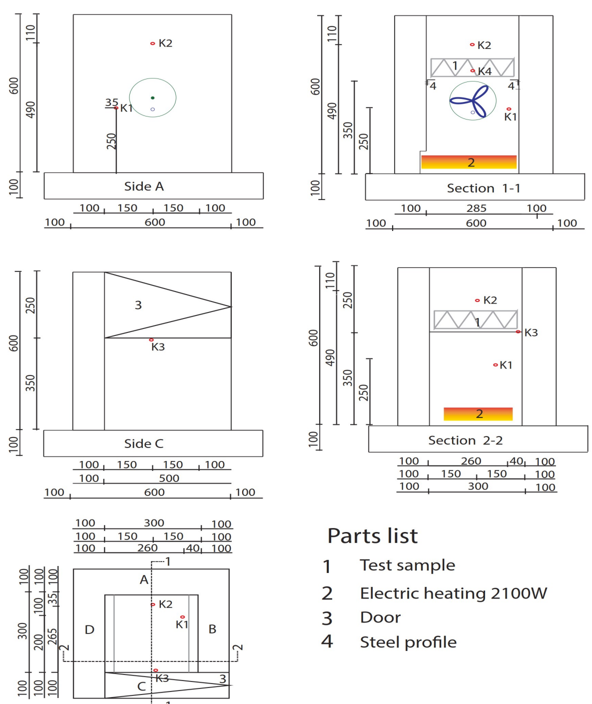
Stills of a video where smoke is burnt inside a bottle

Fire behavior of sandwich panel core materials in the pre flashover phase

Sander Giunta d'Albani

Winner IFV-VVBA Thesis Award 2015

For this research, focussing on the pre-flashover phase of a fire (<400 °C), a special furnace has been designed and built, which has the capability to one-side exposure of sandwich panels and their core materials (stone wool, PUR, PIR, EPS and XPS). The research shows that delamination can occur due to degradation of the resin between metal facings and the core. In case of PUR and PIR, delamination can also occur due to the gasification of the core material.



Experimental setup

The mass losses measured in the experiments where the samples were exposed from one side were 7%, 29% and 83% at a temperature of 350 °C for stone wool, PIR and PUR sandwich panels respectively. These values are valid for the visible damaged area of the samples; the visible intrusion depth of the damage and other results can be found in Table VI. The mass loss of PUR was slowly linearly increasing for temperatures up to 300 °C, but a rapid mass loss occurs from this temperature onwards due to gasification of the PUR core. The mass loss of PIR shows the same course as PUR being stable up to 300 °C but higher mass loss rate from 300 °C and onwards; however, mass loss is lower than PUR. Stone wool panels show a linear mass loss rate throughout the experiment.

Furthermore, the progress of the degradation front at a different temperature was clearly visible when the sandwich panels were cut into two parts.

The flammability ranges for the different insulations core were determined experimentally. The lower and upper flammability ranges for PUR are 9.2 and 74% m/m respectively. A lower flammability for EPS and XPS of 3.1% m/m was found, but during the experiments, the upper limit as not found. The effluent of the heating of stone wool and PIR cores could not be ignited during the experiments.

Table VI. The mass loss (in gram) and the intrusion depth of the degradation front and mass loss percentage at 350 °C during the mass loss test.

Core type		PIR	PUR	Stone wool wall	Stone wool roof
Mass loss (g)	150 °C	1.72	1.05	1.17	1.78
Mass loss (g)	250 °C	2.4	3.32	2.3	2.45
Mass loss (g)	350 °C	8.92	15.12	5.22	4.63
Intrusion depth (cm)		1.61	1.52	1.69	1.65
Core mass		30.97	18.31	66.83	71.45
Mass loss		8.92	15.12	4.63	5.22
Mass loss % of core		29.0	83.0	7.0	7.0

PUR, polyurethane; PIR, polyisocyanurate.

A simulation of a fire event in a storage building, using Ozone, revealed that even in the worst-case scenario, the LFL of 9.2 % m/m will be reached by the insulation material (PUR) alone during the pre- flashover phase (<400 °C). Exceeding this LFL is even more likely by a combination of pyrolysis of insulation material and the fire load near the fire in the fire compartment during this phase of a fire. This introduces a risk of a smoke layer explosion, a hazardous situation for the fire brigade in case of an offensive intervention in the fire compartment.

Table VIII. The results of the simulations when applying the different sandwich panels.

Storage building	PUR	PIR	Stone wool
Mass loss (kg)	325.9	250.2	156.0
Mass loss of influenced area (%)	3.14	1.57	0.74
Pyrolysis gas smoke layer ratio (kg/m^3)	0.06	0.05	0.03
Pyrolysis gas smoke layer ratio (kg/kg)	0.12	0.09	0.05
% pyrolysis mass of total smoke layer mass	11.31	8.2	5.2

PUR, polyurethane; PIR, polyisocyanurate.

Fire safety and suppression in modern residential buildings

Vincent van den Brink

Nominated IFV-VVBA Thesis award 2015

During their daily activities the fire service observed that there is a trend that glass fallout occurs at a later stage of the fire. The extended period of time before the window pane fallout has major implications for the fire behaviour, and therefore also the strategy of the fire service. As a result, it is expected that the fire service will face more ventilated controlled fires in the near future, which result in a faster increase of the temperature, the production of more toxic gases whereby the survivability for the occupant decrease dramatically. The occurrence of a quick increase of the Rate of heat Release (RHR), backdraft, smoke gas explosion or a sudden window pane failure as a result of high pressures might result in more casualties among fire fighters. The Dutch building code will prescribe that in the year 2020 all buildings must be energy neutral. An insight in the consequences for the safety of the occupant and fire service is therefore essential.

In this research, a study to the influence of the building skin on the fire behaviour, and in particular the pressure increase during fire in well insulated and airtight dwellings, is carried out. This makes it possible to make statements about the safety of the occupant and the fire service during suppressive actions in modern dwellings. The literature study identified that the pressure build-up mainly depends on thermal expansion. The thermal expansion is determined by six concrete variables which are the Rate of Heat Release (RHR), amount of infiltration (qv;10 value), volume of the room, mechanical ventilation, type of enclosure and the Rc- value of the enclosure. The qv;10 value, size of the compartment and the RHR have the largest influence on the pressure behaviour.

It appeared that on the basis of the simulation programme Ozone, it is difficult to give an insight in the fire and pressure behaviour of well insulated and airtight dwellings as a flow exponent of $n \neq 0.5$ cannot be applied. The magnitude of the air flow is calculated at a fixed pressure difference of 10 Pa and an oxygen dependent combustion model is lacking. With regard to the first two aspects an iterative calculation tool is developed to make a closer approach for the pressure behaviour. However, it appeared that this results in an underestimation of the pressure. For the simulated scenario in an enclosure of 4.0 x 5.0 x 2.6 m (l x w x h), this results in a pressure peak of 64 Pa. As a result of the stochastic deviation of the variables and a lack of knowledge about practical situations, it can be expected that the pressure peak of 64 Pa will be exceeded. A multiple linear regression model is used to develop an equation to predict the pressure peak within a range of the variables of +/- 50% with regard to that scenario in practical situations.

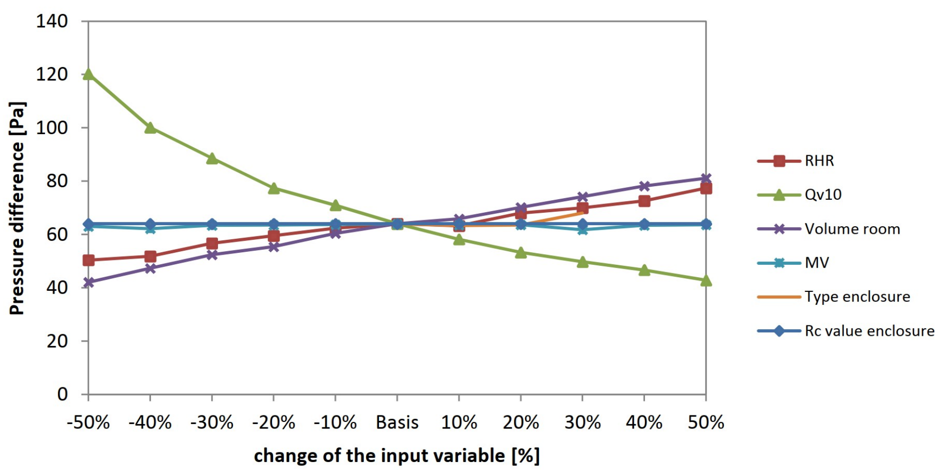


Figure 16 Sensitivity of pressure difference given the variation of the 6 different boundary conditions

The results of the conducted experiments show that that high pressures in the order of hundreds of Pa can occur during fires in passive dwellings. But also for well insulated dwellings significant higher pressures are observed. In the situation in which the amount of infiltration is doubled with regard to the maximum amount of infiltration according the passive house standard, still a pressure peak is 173 Pa observed.

Although in theory a ventilation controlled fire can be expected in modern dwellings, in practice the fire and pressure behaviour will be determined by coincidental factors like opened door and windows. Therefore, the fire service can expect a wide range of scenarios. The pressure peak will occur before arrival of the fire service at the fire scene and will therefore have no direct influence on the safety of the fire service.

The high pressures will have an influence on the safety of the occupant as the pressure peak will occur during the fire growth stage. This may prevent the occupant to escape the dwelling as it will be difficult or even impossible to open inward turning doors. In combination with the strong temperature increase this will lead to fatal circumstances within a minute.

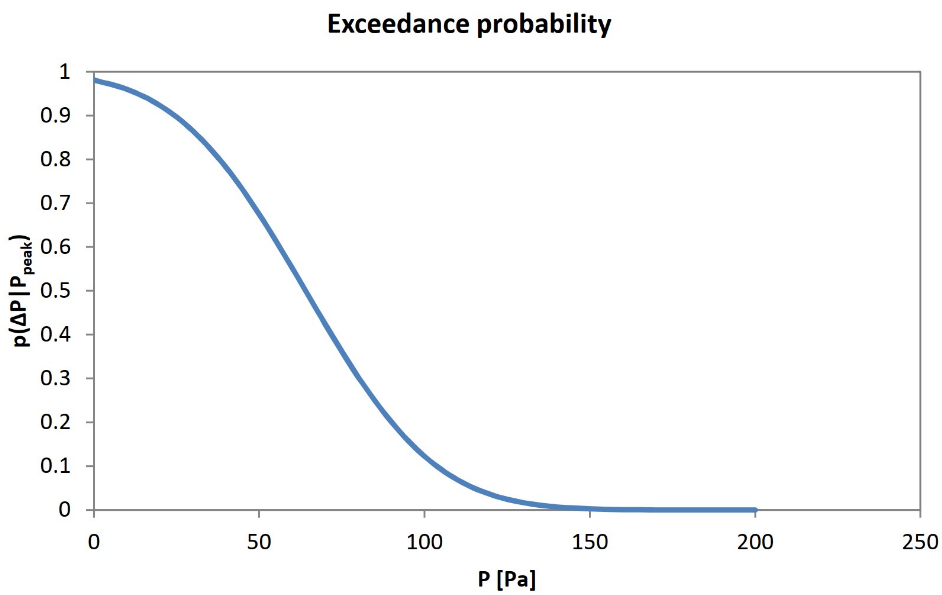


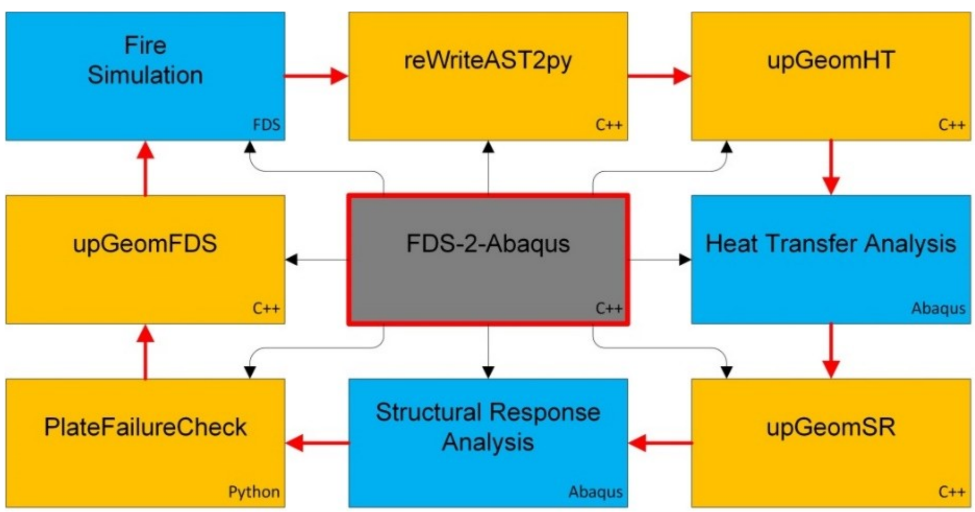
Figure 17 Exceedance probability

Two-way coupling of CFD fire simulations and FE modelling on thin walled steel structures

Jelmer Feenstra

Winner IFV-VVBA Thesis award 2016

For the global modelling of building structures, that is, the modelling of the overall topology of the structure, not limited to certain connections or components, the coupling of CFD fire simulations and FE thermo-mechanical models can be carried out by either one-way coupling or two-way coupling. Unlike one-way coupling, two-way coupling considers the effect of the structural response on the fire propagation, an effect that so far has only been studied for a very limited number of cases.

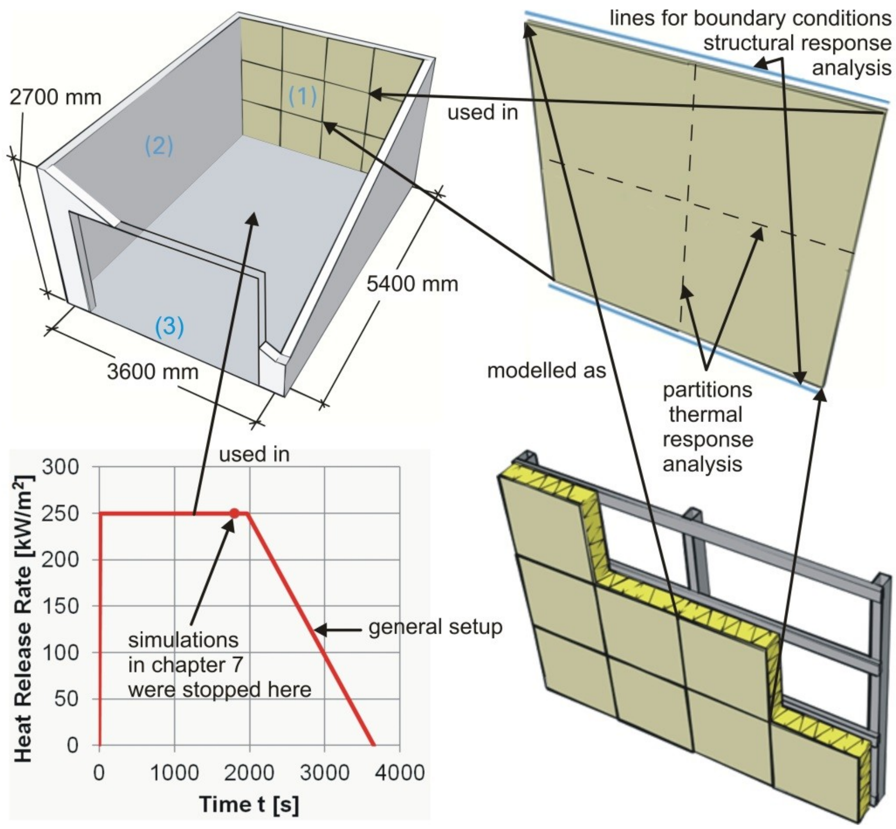


Implementation of fully automated two-way CFD fire-FEM thermo-mechanical coupling

The first part of this paper investigates the feasibility of two-way coupling. Its components, fire simulation, heat transfer analysis, and structural response analysis are introduced first. These components are coupled by three steps:

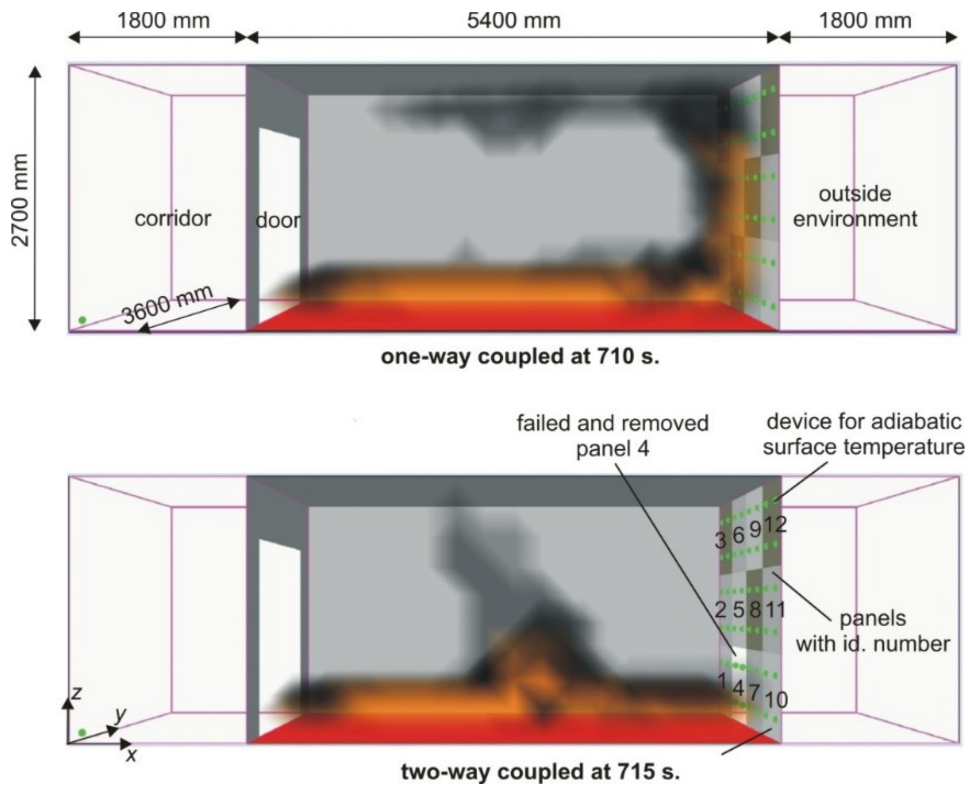
i. coupling of fire simulations to heat transfer analysis;
ii. coupling of heat transfer analysis to structural analysis; and
iii. coupling of structural response to fire simulation, in which the latter is unique for two-way coupling.

Then the implementations of these couplings in C++ and Python are described in this paper. Finally, the setup of a master program in C++ is explained to automatically control the couplings and the programs of the components (FDS for fire simulation and Abaqus for heat transfer and structural analyses).



Model room (top left) uses steel plates (top right) modelled from a sandwich panel system (bottom right). Room fire is based on graph bottom left

Using this implementation, the second part of this paper shows the practical differences between one-way and two-way coupled analyses for an office space in fire that results in failure propagation of its thin-walled steel building façade. Although the results differ slightly for each of the several simulations due to random effects in the fire simulation, overall results are quite comparable. It can then be concluded that the implementation and the significant difference in failure progression of the facade illustrate the feasibility and the effectiveness of two-way coupling, respectively. However, further research to develop more advanced fire and structural models and validating them using experiments is required for an all-conclusive answer.



Smokeview visualisations: failed panel # 4 causes the fire to move to the centre thereby reducing the load on the remaining panels

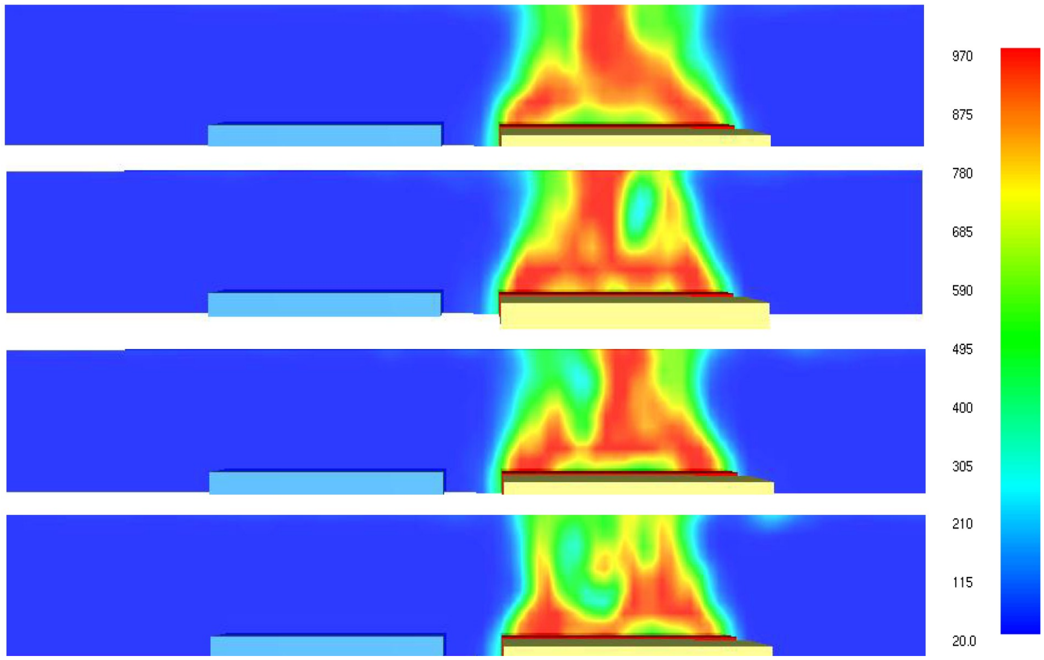
Fire propagation in an open carpark

Babette Mattheus

The goal of this thesis was to obtain more knowledge on the use of a new heat release rate (RHR) scenario, created in a research at the Delft University of Technology, in large car parks. And the possibilities in Fire Dynamic Simulator (FDS) to calculate the propagation time between two cars in the model instead of using an imposed time and the influence of the distance between the parked cars on the propagation time. The thesis was therefore divided into two parts, an analysis and a research.

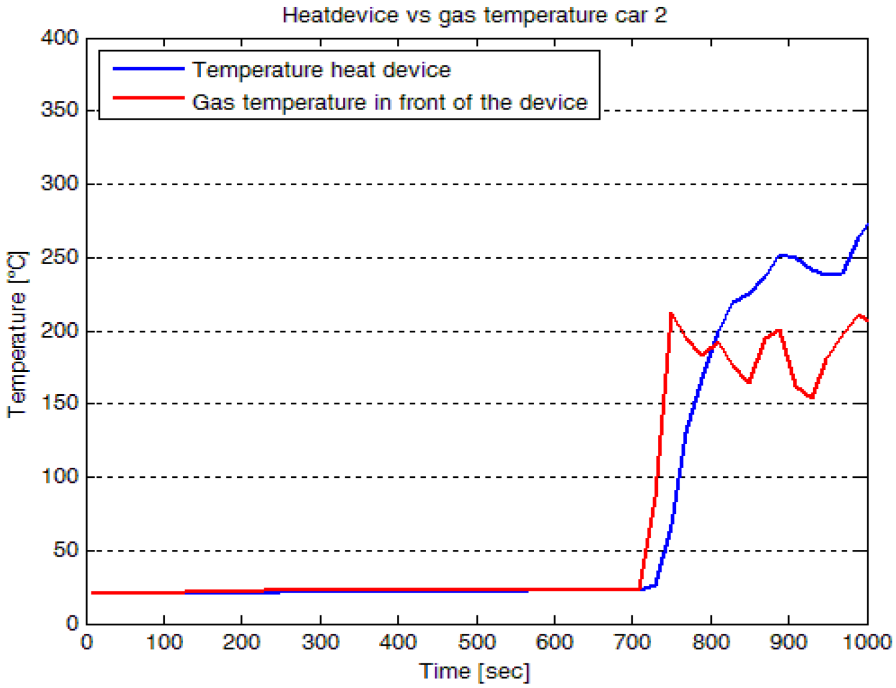
In the first part an analysis was performed on the car park of the Designer Outlet Center (DOC) Roermond, a project of consultant engineers Nieman. In this project a calculation of the material temperatures of a steel beam was performed in Car Park Fire (CaPaFi) and FDS. The results were contradicting to the expectation because the results from FDS were more conservative than the results of CaPaFi. In this project the RHR scenario of the TUDelft, based on the RHR scenario of CaPaFi, was used.

The analysis focuses on the use of the fire scenario of the TUDelft in the DOC model and showed that there were five differences in the FDS scripts regarding the fire scenario. The difference with the most influence was the rate of heat release per unit area and with the correct adaption of this difference the results met the expectations.



Cross sections of FDS simulations with meshwidth 5 cm after 25, 50, 75 and 100 seconds

Also in the analysis a test of the effect the smoke development and radiation on the temperature development was performed. It showed that the radiation is modelled according to expectations but the smoke development shows no effect on the temperature this contradicting expectations, because it would mean that the radiation flux of the smoke particles are not significant.
In the second part of the thesis a research of the possibilities of the propagation time in FDS was performed. With a new model where heat devices (heat switches based on gas temperature) were implemented the possibilities of these devices were tested. To fit the propagation time with the CaPaFi scenario, unrealistic low gas temperatures were obtained. Resulting in a large uncertainty in propagation time, due to the large eddies near the burning car, even when the cars were linked to multiple heat devices.



Besides the heat devices also the radiative heat flux was tested as a propagation criterion. But also the results from these devices were too instable to link to the ignition of the surrounding cars. Because ignition depends on both radiation flux and material properties, especially heat capacity of the adjacent car. A final research with surface temperatures as criterion shows that, although these temperatures are stable, the rate of heat release is not detailed enough implemented to calculate a reliable propagation time. Therefore it is not possible to realistically test the effect of the distance between the parked cars on the propagation time in CFD.

Numerical simulation of external flames in ventilation controlled post flashover fires

Reem Shakerchi

One of the fastest ways of fire spread to other floors is via external openings along the façade (Mammoser & Battaglia, 2002). This way of fire spread is the most dangerous because it is difficult to recognize by the building users. Fire CFD simulations are increasingly used for improvements in the fire protection and the fire safety engineering for reducing and preventing fire victims in the building environment.

External flames occur as results of a limited oxygen concentration inside the enclosure. Unburned gases will then burn outside the enclosure along the façade with enough oxygen concentration. When external flames occur the heat release rate (HRR) outside will result in higher temperatures and heat fluxes. The emitted radiation from the enclosure fire will increase the façade heat fluxes by decreasing the distance. Therefore reducing external flaming is necessary to reduce the risk of fire spread to upper fire compartments. In this research Computational Fluid Dynamics (CFD) simulations with external flames are performed for understanding the sensitivity of external flaming. By using CFD simulations it is possible to estimate the influence of different building and/or fire parameters on the external flaming behaviour.

Due to several complex variables in CFD calculations which depend on the fire scenario, the simulation should be validated with measurements of similar fire scenario. Therefore a CFD simulation model with external flames of ventilation controlled fire is validated based on a literature study (experimental and numerical). An own validated simulation model is used as a reference model to investigate the influence of different building and fire parameters on the external flaming.

Validation study

To investigate which grid cell size is minimal needed to reproduce accurate simulation results a grid sensitivity analyses is performed. Two grid cell sizes (2 cm and 1 cm) are simulated and compared to the measurements. All mentioned measured variables show a lower deviation with the measurements by using 1 cm grid cell size rather than 2 cm. Using 1 cm grid cell size shows a new empirical correlation of 1350 Affl(H) for the actual HRR. This means the simulated actual HRR inside the model deviates approximately 10% from the measurements. The simulated mass inflow rate shows an empirical correlation of 0.47 Affl(H) (deviation of approximately 6% with the measurements). The simulated neutral plane height shows agreement with the empirical correlation of 0.4H. For determining the external flame height from the flame temperature distribution two calculation methods are introduced in this research. Both calculation methods are compared to the external flame height from the experiments. From the results it can be concluded that using calculation method 1 gives a good agreement with the measurements. Because measured data always deals with certain measurement uncertainties the deviation of maximum 10% between the measurements and the simulations is accepted in this research for the validation of the CFD model.

Full-scale real fire compartment

The cubic scale model with adiabatic constructions (from the sensitivity analyses) is expanded to a full-scale fire compartment (factor 10) with a door-like opening and cellulose fire. The full-scale model is simulated by two different grid cell sizes to investigate the grid sensitivity on the results compared to the reference model.

The results of the actual HRR and the mass inflow rate show small differences between using 10 cm grid cell size or 5 cm grid cell size. This means that using similar ratio for the grid cell size in the full-scale model is possible.

Except the results of the neutral plane height are not similar. The results are even less accurate by using a finer grid cell size. The full-scale model is simulated with cellulose fire instead of propane fire so the results may give another empirical correlation than the empirical correlation of the reference model. Therefore a third new full-scale simulation models (with 10 cm grid cell size) is simulated with propane fire to investigate if the results of the actual HRR and the mass inflow rate will fit the empirical correlation of the scaled reference model. The results of the actual HRR and the mass inflow rate shows a deviation within 10% with the reference model by using propane fire instead of the cellulose fire. To investigate if a finer grid cell will result in a lower deviation with the results of the reference model a new simulation model with a lower grid cell size should be simulated.

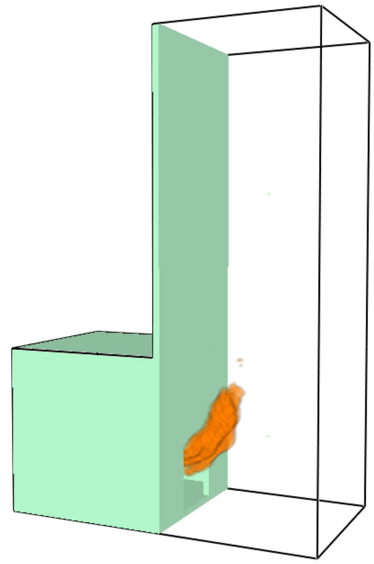


Figure 26: A screenshot of the CFD model with external flames (real fire compartment.

Cooling of a hot smoke layer by a sprinkler spray

Nick Tenbült

Winner IFV-VVBA Thesis award 2018

CFD models are increasingly used in building design. In the context of fire safety engineering CFD models have proven to be useful for the prediction of smoke transport in buildings in case of a fire. In a fire scenario where sprinklers are activated the temperature and movement of the smoke layer is subject to the sprinkler spray. Fire suppression by a sprinkler spray can be distinguished in three regions, namely the interference of water droplets with the fire plume (flame), smoke plume and smoke layer. This graduation project focused on the interference with the smoke layer.

By spraying water directly into a smoke layer it may cause diffusing and descending of the smoke. This phenomenon is called smoke-logging and was introduced by Bullen in 1974. According to Bullen, the stability of the smoke layer depends on the ratio between the drag force (D) and buoyancy force (B) on the smoke layer. Smoke logging will occur when D>B, otherwise the smoke layer will remain stable. Smoke logging can potentially result in a decrease of the efficiency of a smoke extraction system and compromised egress routes.

In the past, the effects of water droplets on a smoke layer has been studied with numerical models and experiments. The volumetric flow rate of smoke going upwards decreases under sprinkler spray due to the cooling effect of the water droplets. So far, numerical simulations are performed with an evenly distributed water mass and velocity within the spray envelope. However, separate studies by Sheppard and van Venrooij indicate irregular water droplet distributions within the spray envelope for both elevation angle and azimuth angle, which is strongly dependent on the nozzle's geometry. Further development of the CFD-models and more experimental data is required to validate the CFD-models.

Experiments

The experimental set-up (Figure 1) is based on earlier conducted studies with similar research objectives. The set-up consists of two connected cabinets. In the combustion cabinet smoke is generated by a fire. The smoke flows into the smoke cabinet where a smoke layer is formed. The smoke is extracted by a mechanical fan. In the exhaust duct the smoke is analysed to determine the heat release rate (HRR) of the fire. When a stable smoke layer is formed the sprinkler spray is activated to cool the smoke layer. Smoke and heat are generated by pool fires. In total nine experiments were performed, with heptane as a fuel, for two different pool sizes (0.25 m^2 and 0.35 m^2).

In the middle of smoke cabinet, a pendent sprinkler nozzle is placed at a height of 2.9 m. The sprinkler with an orifice diameter of 11.1 mm has a K-factor of 80.6 and a 25 mm deflector plate diameter. The sprinkler spray is activated manually and the operating pressure at the sprinkler nozzle is controlled by pre-set pressures at the pump's frequency controller.

The smoke cabinet is equipped with a thermocouple array. To prevent the thermocouples from wetting, aluminium conical shields were placed above the thermocouples. The combustion products are analysed in the exhaust duct to determine the HRR with the Oxygen Consumption Calorimetry (OCC) method.

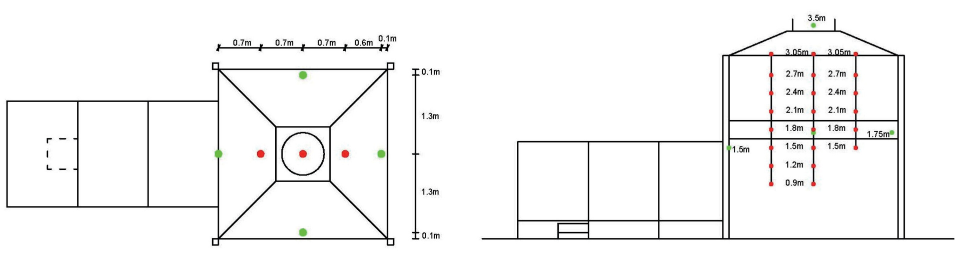


Figure 1. Positions of thermocouples; top view (left) and side view (right)

Numerical model

The flow of a fluid can be described by the Navier-Stokes equations, a system of partial differential equations. For the modelling of turbulence FDS uses the Large Eddy Simulation model (LES-model). In this approach transport equations are solved for the large eddies and an eddy viscosity model (turbulence model) is used to model small eddies.

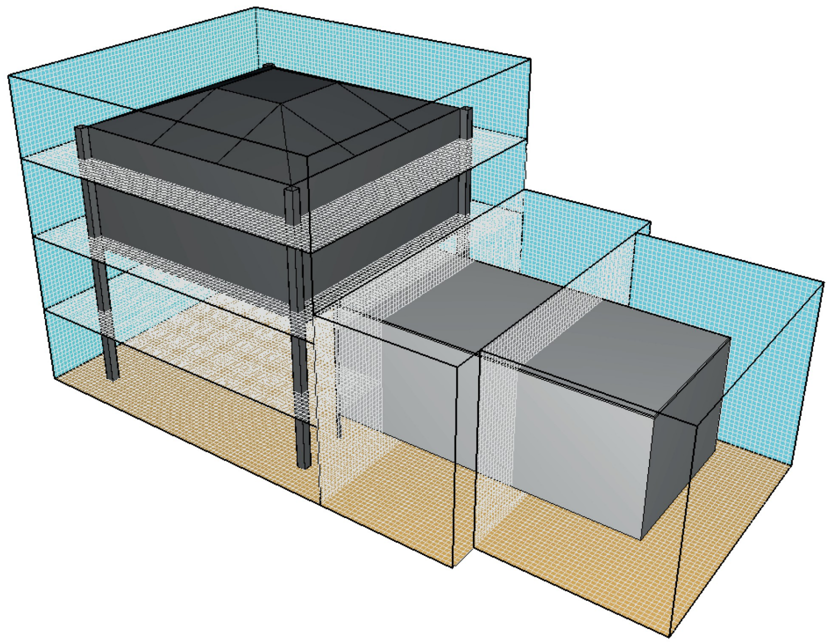


Figure 2 - Computational domain divided in sub-grids for MPI processing

Bucket tests in an open space are performed to model the sprinkler pattern. A mathematical model is used to translate the water collection at the floor into the above-mentioned injection properties for the spherical injection surface. The 'spray table' is implemented in the FDS-model to model the sprinkler spray. The results of the bucket tests are compared with the FDS predictions and subsequently the spray pattern table is improved by 'trial-and-error'. The spray table of the best-fitted results is used in the final simulations.

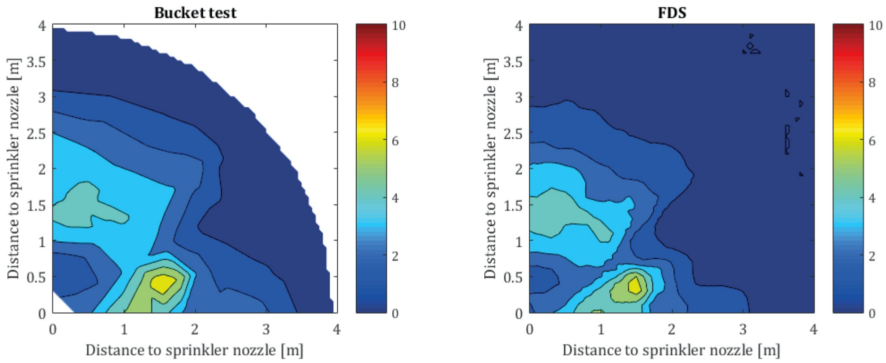


Figure 3. Water collection at floor (lpm/m2), Bucket test (left), FDS (right)

Results

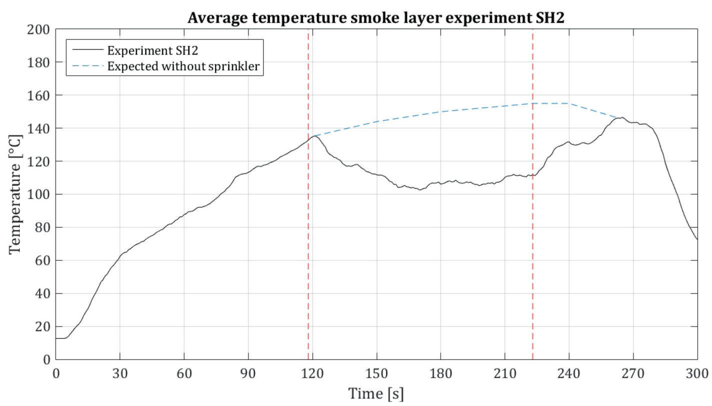


Figure 4. Average smoke layer temperature sprinkler test heptane 2 (SH2)

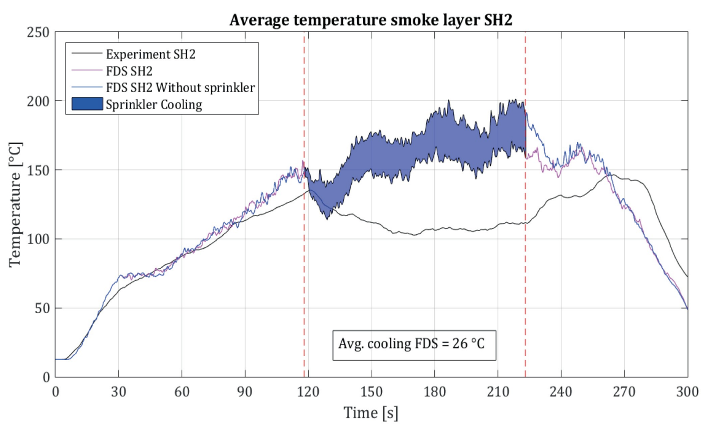


Figure 5. FDS predictions of average smoke layer temperature SH2

Conclusion

This study has shown the limitations of FDS when used for predicting the effects of smoke layer cooling caused by an activated sprinkler nozzle. Multiple experiments with and without sprinkler activation are performed and thereafter simulated with FDS.

Figure 7. Smoke logging, water flowrate 56, 71 and 93 l/min

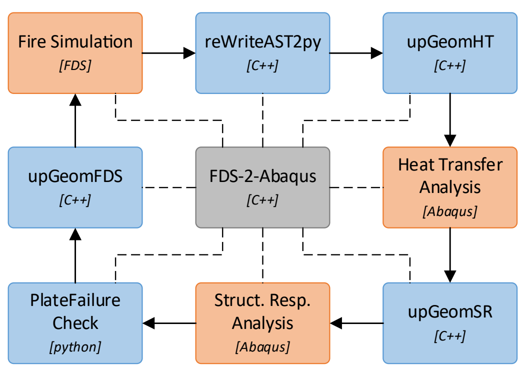
The injection of water droplets into the sprinkler spray reduces the smoke layer temperature. The experiments show that increasing the water flow rate of the sprinkler nozzle result in a larger temperature decrease. The thickness of the smoke layer increases within the sprinkler spray envelope. A water flow rate, with relative large droplets, causes a very small amount of smoke logging, where a flow with smaller droplets, result in an unstable smoke layer and significantly reduced visibility. It can be concluded that smaller droplets amplify the downward smoke displacement. All simulations that have been done with FDS underpredicted cooling by the sprinkler spray. The spray pattern that was modelled corresponded with a measured water distribution at the floor surface. Simulations with a low-detailed, simple spray pattern did not result in significant differences for the smoke layer cooling. Regardless of the level of detail from the sprinkler spray, the models embedded in the FDS code to solve the numerical equations are not capable of predicting the smoke layer cooling by water droplets.

Automated two-way coupled CFD fire and thermomechanical FE analysis of a self-supporting sandwich panel facadesystem

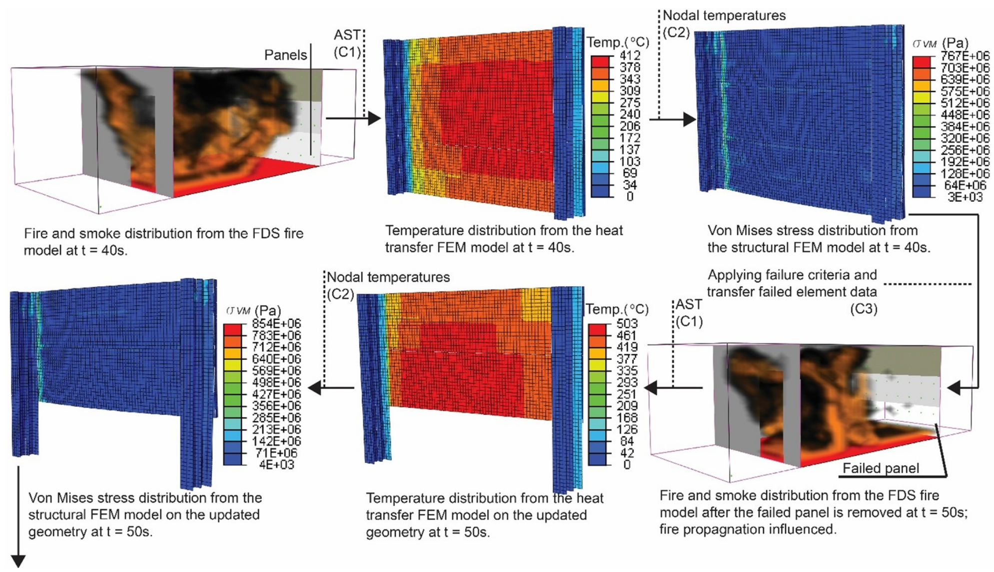
Jan de Boer

To achieve a safe design for a façade system during a fire, design rules can be applied. The system's temperature is then predicted as a function of a fire temperature curve, and hereafter for each element of the system a critical temperature is determined. Alternatively, a computational analysis can be carried out, which starts with a fire simulation using Computational Fluid Dynamics (CFD), followed by a heat transfer and structural response analysis by using the Finite Element Method (FEM). In this paper, a self-supporting sandwich panel façade system under fire is studied.

First using a variant of the design rules approach, a thermomechanical FEM model, which comprises the complete façade system and incorporates material degradation and geometrical nonlinear behaviour, is loaded by a fire temperature curve. Eurocode design rules then predict the connections of a sandwich panel to fail, which leads to the panel to fall off. As this type of structural failure requires a computational analysis, then the program FDS-2-Abaqus is extended to allow its two-way coupled analyses, in which CFD fire simulations are updated for changes in the structural model, to be applicable to the self-supporting sandwich panel façade system.

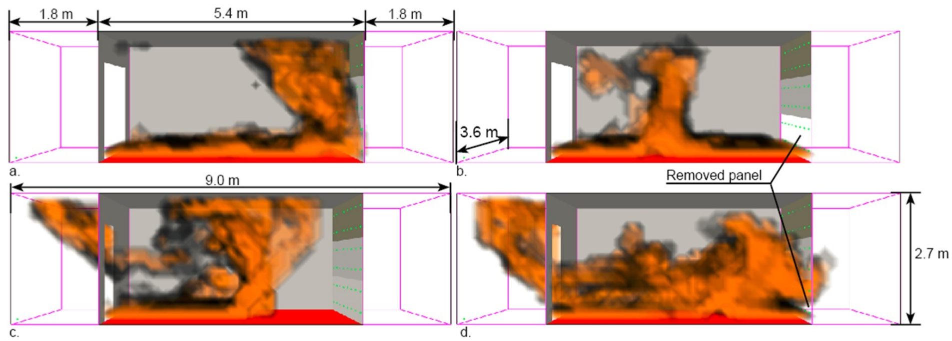


This study shows that such an analysis has advantages in predicting realistic behaviour compared to a one-way coupled CFD-FEM analysis and to the design rules approach: By means of parametric studies, it is shown that improved screw properties do not change the panel failure order, however, they improve critical times, and even can avoid failures at all. Using for the connections displacement-based instead of force-based failure criteria, the panel failure sequence does not change, but displacement-based criteria result in slightly delayed failure. Before panel failure, for a fuel-controlled fire, the fire is located close to the façade, which leads to high temperatures at the façade and to quick failure. While for a ventilation-controlled fire, the fire is located more in the centre of the room, relatively saving the façade. After the failure of the first panel, the fuel-controlled fire is now located in the centre of the room, while for ventilation control a high heat release rate results in subsequent panel failures.



A typical two-way coupled CFD-FEM analysis in which one panel fails

Finally, it is shown that thermal expansion of the façade panel is governing failure of the screws, while thermal bowing retards screw failure. Thicker sandwich panels have a larger stiffness than smaller panels, which leads to a smaller deflection due to thermal bowing, and therefore thicker façade panels will decrease the critical failure time of the screws. Future research will focus on detailed FEM models for the connections; real life fire experiments; temperature measurement points at the façade outside; advanced PIR core modelling; and the effects of high temperature creep.



Fuel controlled fire at (a) t = 29 s and (b) t = 33, ventilation controlled (c) t = 29 and (d) t = 43 s

Fire safety risk checker: risk factors for residential housing for elderly

Lennart Gerritsen

Fire safety is of significant importance to our society. Each year, people die or become injured because of fires in their houses. In order to investigate this further, the most important fire safety risk factors regarding residential housing were determined by an extensive literature review. The risk factors were divided into human characteristics, fire characteristics and building characteristics. It shows that elderly people aged 65 years and older have an increased risk of injury or death in the event of a fire.

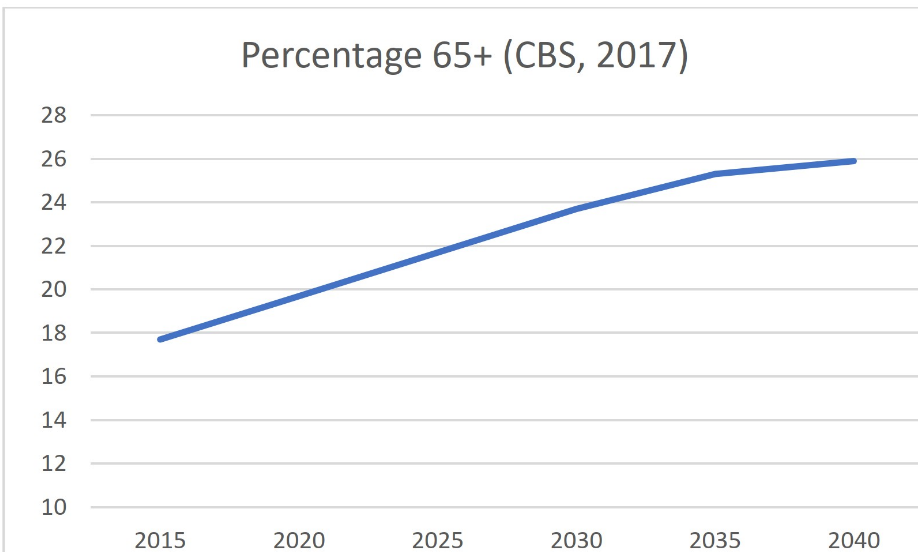


Figure 5: Percentage of people aged 65 or over, compared to the total Dutch population (CBS, 2017)

The reason for this is mainly due to decreased mobility or cognitive disabilities. Furthermore, most elderly live alone and due to governmental policies, an increasing number of elderly people are expected to live alone in the future. This further increases the risk of dying in a residential fire. Elderly people are less likely to notice fire and smoke since they have a reduced ability to smell, see, hear or feel. Moreover, they are less capable to flee independently in case of a fire, due to reduced mobility. The fire characteristics indicated that smoking was the main cause of ignition. Fires that occurred at night and fires that spread beyond the room of origin increased the risk of injury or death. The building characteristics were analysed, as well as the Dutch Building Code. There appears to be no distinction between regular residential housing and residential housing for elderly people in the Dutch building regulations. This is remarkable, since elderly people are less likely to escape independently, without the help of others. They will probably not comply to the minimum requirement of escaping the building within 15 minutes after the discovery of the fire, according to the Dutch Building Code.

An analysis of three major fire incidents in The Netherlands was conducted.

The literature about this was reviewed concerning:

- the human characteristics,
- the fire characteristics and
- the building characteristics,

of fatal residential fires.

An analysis of a fire that occurred in the apartment complex ‘Notenhout’ in Nijmegen at the 20th of February 2015 displayed the vulnerability of elderly people living in regular residential housing. Many occupants needed assistance of the fire department in order to escape their homes. The importance of (smoke-)compartmen-tation came forward, since smoke inhibited occupants from leaving their homes in all three use cases. Of equal importance are fire suppression systems that reduce the spread of the fire, which could be of great help for those who can’t escape the building individually, even though they are warned in time by a smoke alarm. Furthermore, the fire resistance of walls and the availability of emergency exits was brought to attention.

Afterwards, the results from the literature review and the use case analysis was used to determine which fire safety aspects could be queried in IFC files. IFC files can be seen as the open standard for the exchange of building information in the AEC industry, including geometry and object information.

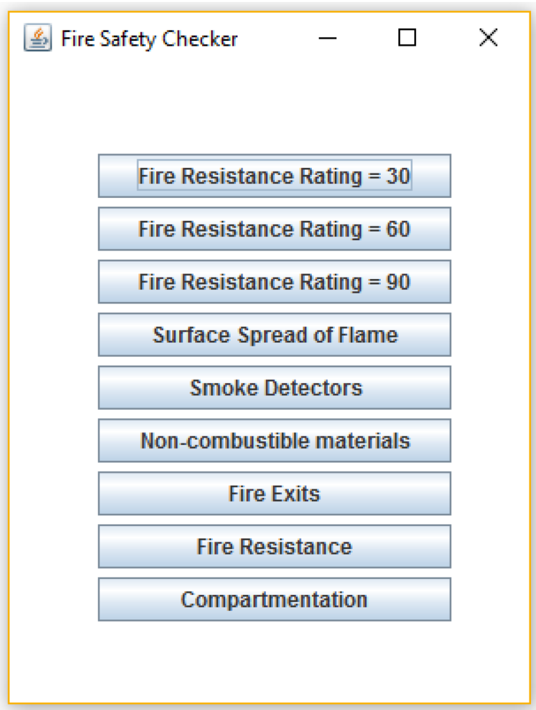


Figure 16: the user interface (window 2)

Therefore, an IFC building model was the starting point for the fire safety checker, to ensure its usability. The fire safety checker was developed by me upon the BIMSPARQL program created by Zhang, Beetz and de Vries 2018. It is difficult to query IFC files directly, due to the data format. In order to enable the possibility to query them, IFC files were converted into RDF files, consisting of triples which include building information. These triples were used to create SELECT query's enabling the search for fire safety aspect such as compartmentation, fire resistance, fire exits, fire suppression systems, surface spread of flames and the availability of smoke detectors within digital building models. Using the fire safety checker does not require programming knowledge by the user. This way, the fire safety checker enables users to get a quick overview of these fire safety aspects in digital building models.

The bearing capacity of an aluminium curtain wall, exposed to a standard fire

Maarten Arntz

The aluminium façade company Reynears Aluminium developed a 30 and 60 minutes fire resistant curtain wall system (CW50-FP) more than a decade ago. The design was based on experimental research. The company has expressed its interest in the redesign of CW50-FP due to changing requirements, such as larger transparency, increase of complex design and increase of performance under external conditions. These requirements can only be met, when the steel elements in the CW50-FP are entirely redesigned in aluminium. However, aluminium has the drawback of a large reduction of mechanical properties at elevated temperatures and this may result in a redesign with a decrease in fire resistance. This context has resulted to the following research questions:

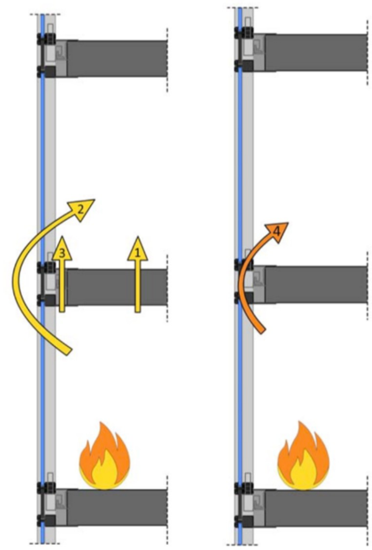


Figure 1.1 A fire expand by four different paths. [62]

i. What is the fire resistance of the bearing elements in curtain wall system CW50-FP exposed to a standard fire [min]?
ii. Can the fire resistance be retained for a curtain wall system using an aluminium glass support and structural profiles made of aluminium?

The design rule to determine the internal temperatures of thermal exposed aluminium structures in NEN-EN-1999-1-2 is curve fitted for light

weighted fire protection materials as mineral wool. Hence, not applicable for heavy weighted protection materials which includes free and/or bonded water. In addition, the classification and examination of the fire resistant curtain wall system given in NEN 6069 and NEN-EN1364 are no longer sufficient for the redesign of system CW50-FP. Furthermore, the determination of the flexural buckling resistance of the aluminium mullion with NEN-EN-1999-1-2 is conservative. This may result in relatively low critical temperature of the mullion.
The aim of present research is to increase the knowledge on the thermal and mechanical behaviour of a fire resistant aluminium curtain wall system when exposed to fire. This to develop a curtain wall system with structural elements of aluminium and sufficient fire resistance. The focus is on the determination of the load bearing capacity of the curtain wall system exposed to a standard fire. In current research this is performed with a thermomechanical analysis, which exists of a thermal numerical model (FE) and an analytical mechanical method. The thermal numerical model is developed with material properties and boundary parameters at elevated temperatures. The mechanical analysis is performed with mechanical schemes, reduction of the yield stress and young's modulus, the influence of thermal expansion and the check on buckling and other member resistances at elevated temperatures.
The thermal study on the redesigned system CW50-FP resulted in a minimal fire protection thickness of 12 mm CX. A surface treatment with a maximum emissivity of 0,7. Internal aluminium temperature below 350 degrees Celsius in non-exposed aluminium elements when the redesigned system CW50-FP is exposed to 60 minutes of standard fire. Furthermore, the redesigned system CW50-FP is structurally analysed. The redesigned transom presents larger vertical deformations than the redesigned aluminium glass supports when the full external load of the fire proof glass is considered. Large deformations in the transom or glass support at elevated temperatures results in direct contact with the underlying glass pane. This changes the force transfer path of the fire proof glass panel to the main structure of the building. In addition, the thermal expansion in the redesigned aluminium mullion and transom

effects the load bearing capacity of the redesigned system CW50-FP when these are restrained.

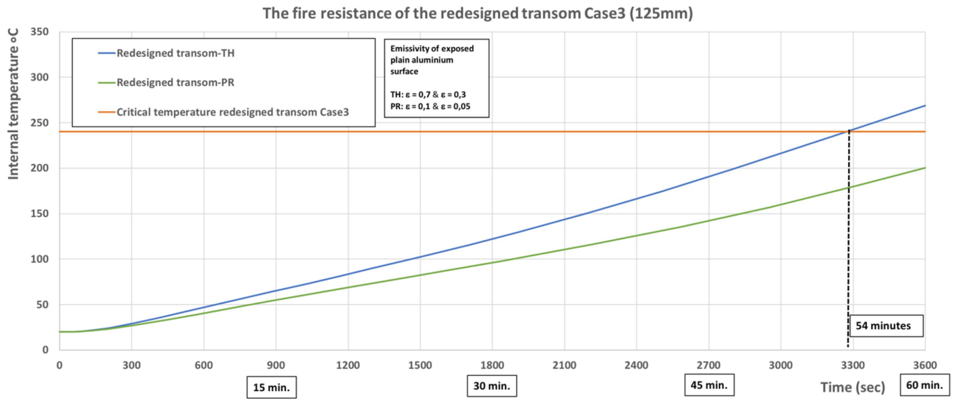


Figure 8.25. The fire resistance of redesigned transom Case3.

Finally, the load bearing capacity of the redesigned fire resistant curtain wall system at elevated temperatures is determined. The redesign consists of an aluminium mullion, transom, glass support and is protected with fire protection material CX. The fire resistance of redesigned system CW50-FP is significant higher as the current system CW50-FP.

Fire safety and the ageing population: a probabilistic link of preventive and repressive measures in residential buildings

Mike van der Linden

Research shows that the fire service often arrives late at an incident location and cannot meet the stated response times. A large part of the fire service organization consists out of volunteers. More and more fire stations have too few volunteers to turn out quickly. Nevertheless, research shows that various rescues are carried out by the fire service every year. The fire service is nationally the only organization that can carry out an intervention in the Netherlands.

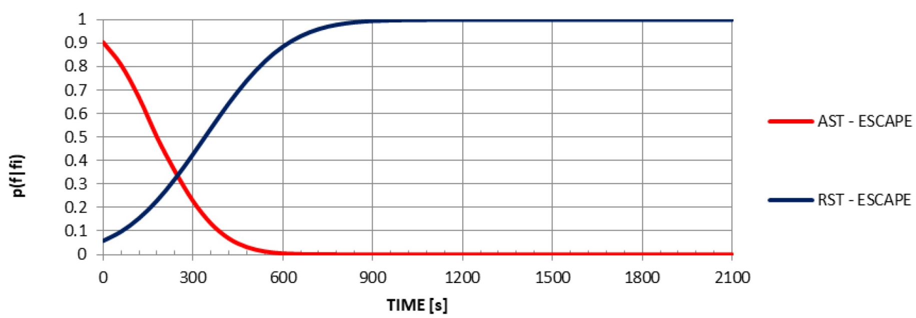


Figure 5-1: Probability distribution of AST-1 and RST-1 of the living room in the gallery flat.

With the help of an available safe time (AST) and required safe time (RST) analysis, research is being done into the problems surrounding fire safety among the elderly. Preventive and repressive measures are defined based on the most important factors form the problem analysis. The research was conducted probabilistically. This means that various

variables are taken into account. An average situation is assumed where uncertainties are included.
To determine the AST are various simulations were performed in CFAST. Two different cases are selected for this research. The simulations are performed in a gallery flat apartment and an apartment complex apartment. A fire is simulated in the living room with a sofa as start object. This fire will develop into a flashover.
A distinction has been made between two AST scenarios and two RST scenarios. The required safe time (RST-1) for an independent escape attempt is compared with the available safe time (AST-1) for an independent escape attempt. The required safe time (RST-2) for intervention by the fire service is compared with the available safe time (AST-2) to survival a fire.

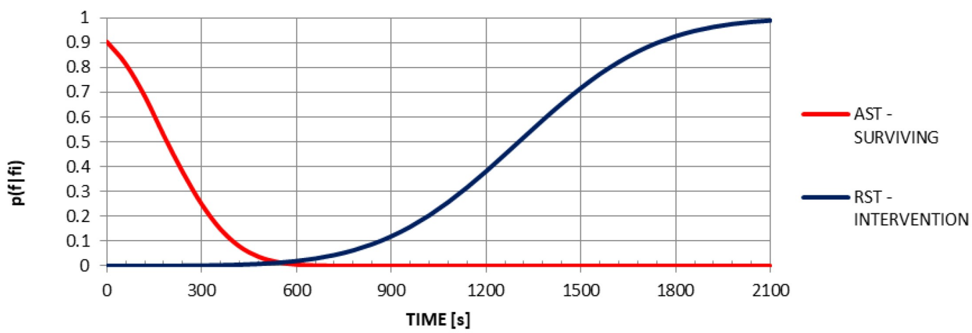


Figure 5-2: Probability distribution of AST-2 and RST-2 of the living room in the gallery flat.

Increasing the smoke detector density is a relatively simple measure that can positively influence fire safety. Placing an extra smoke detector in the living room and in the bedroom appears to be an effective solution to alert older people faster.
Fire retardant furniture is the only measure that positively influences the room conditions in the fire room. It extends the available safe time in all areas. The position of the interior doors influences the conditions in the rooms that are separated from the fire area. A closed door between the fire room and another room ensures that the AST is increased.

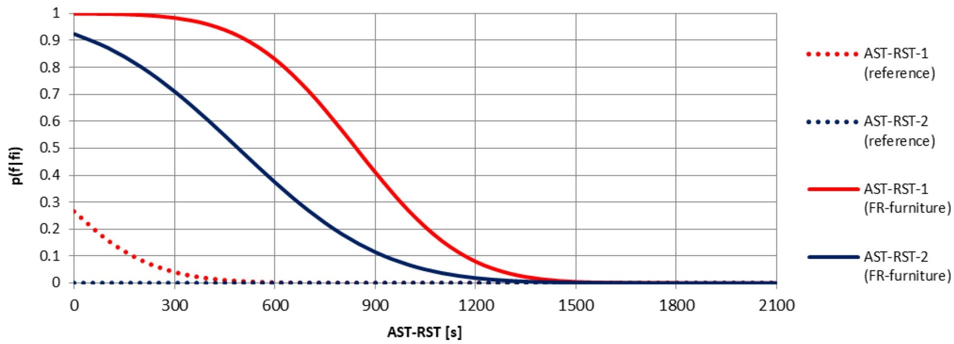


Figure 7-7: AST-RST in reference situation and with fire retardant furniture.

Switching to area-specific response times can provide more certainty about the response times of the fire service. If it is clear that the fire service has a longer response time, additional measures can be applied to increase fire safety.

Deploying neighbors or civilians seems to be an effective and complete new solution. Neighbors or civilians can be alerted with the help of smart smoke detectors. If they are alerted, they can quickly report a fire to the fire service if necessary. In some cases they will be able to perform an intervention by extinguishing a fire or carrying out a rescue. Further research will have to show the feasibility of this solution. The police and the ambulance are already using civilian assistance.

Preventive measures are much more effective than repressive measures. It is important to continue to invest on both sides. As long as there are no good alternatives, the role of the fire service remains important.

Different concepts for personal safety in a multi-storey residential building, related to internal smoke propagation

Marc Scholman

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.

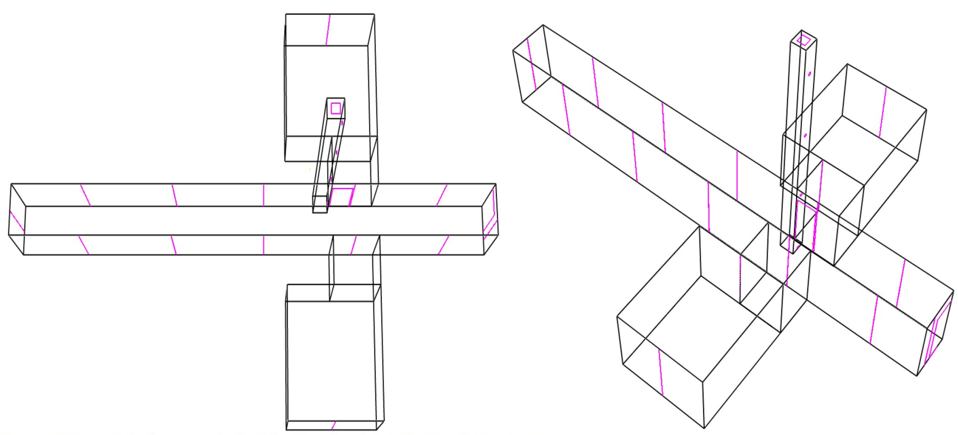


Figure 3-3 Isometries (wire model in 3D) of the simulated situation in Smokeview.

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.

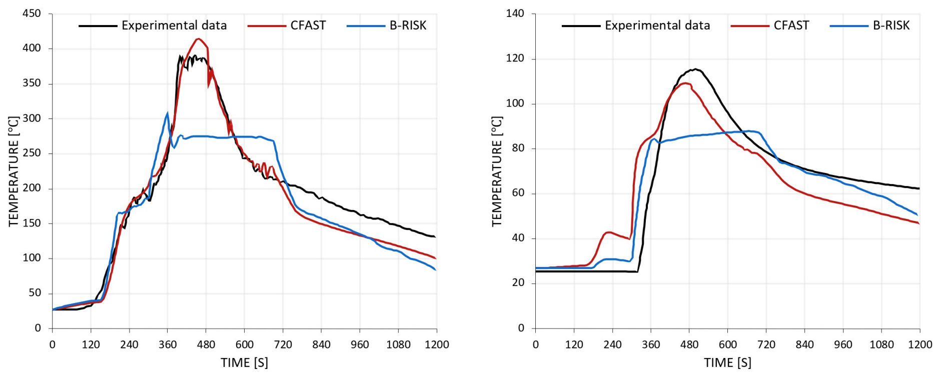


Figure 3-5 Upper layer temperature in apartment 1.19 (left) and upper layer temperature in corridor 1.29 (right).

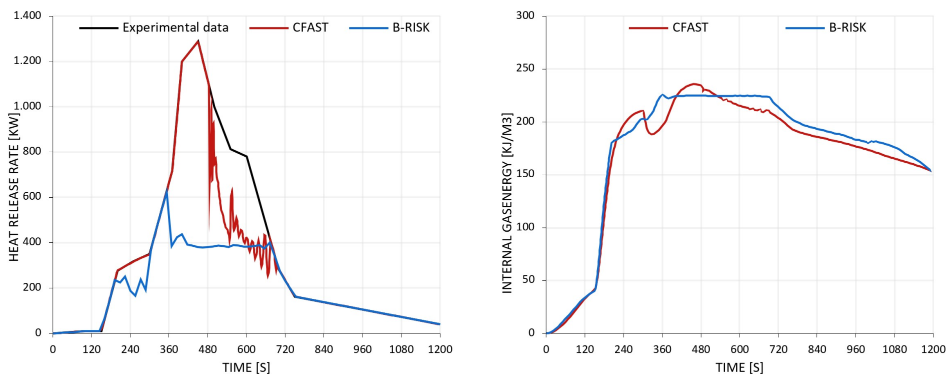


Figure 3-7 Actual heat release rate [kW] during experimental fire test (left) and internal gas energy smoke layer [kJ/m^3] in apartment 1.19 (right).

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.

Thermomechanical modeling of composite slab joints under fire

Sue Ellen de Nijs

Nominated IFV-VVBA Thesis award 2022

When the temperature of concrete and reinforcement steel increases, strength decreases. Since the detail of the coupling reinforcement in a composite floor is already critical, a temperature increase at this specific location could become more critical for structural reliability. Therefore, this paper focuses on researching the temperature of the coupling reinforcement in a composite floor caused by fire conditions, which are based on ISO 834, underneath the floor.

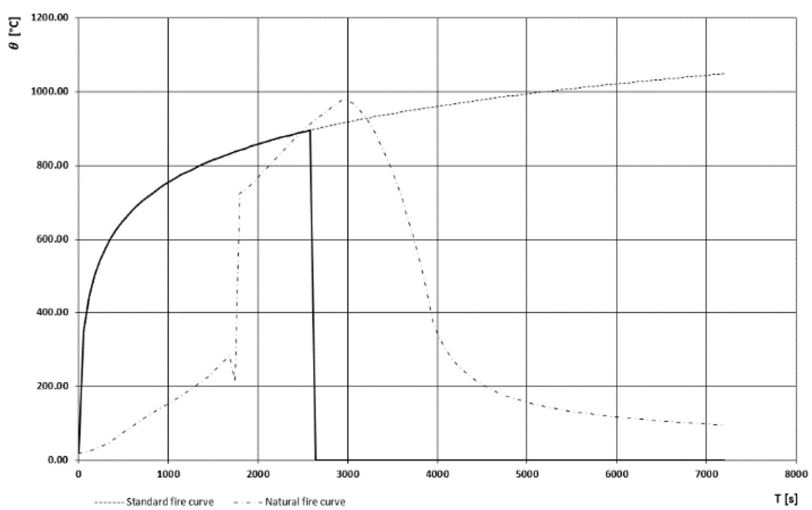


Fig. 6. Standard fire curve and natural fire curve. *[5]*
curve. By making this translation the energy of both curves is equal.

To answer the research question, a numerical model of the heat transfer in the composite floor was created which incorporates convection and radiation according to the EN 1992-1-2. This model was verified by developing graphical analytical, and numerical analyses which are based on a simplified model designed for this research. The reinforcement bars in the composite floor are not present in the model, because it was assumed that the reinforcement temperature is equal to the temperature of the concrete.

It was essential for the research to review the temperature of the joint in different dimensions and thicknesses for the precast plate in different periods since it is possible to use the composite floors for different purposes. By evaluating the results of the numerical analyses of a composite floor, it became clear which situations could form a risk.

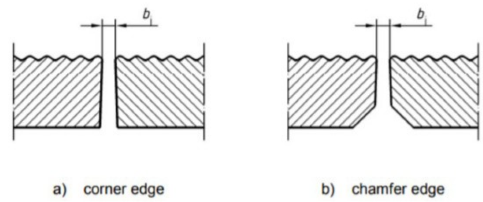


Fig. 1. Examples of current joint profiles with b_i. *[2]*

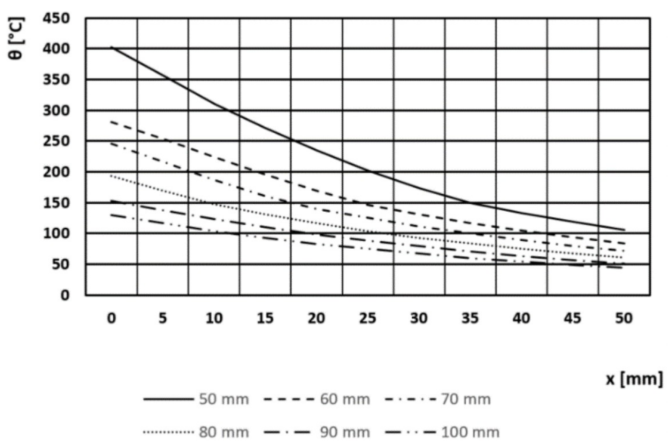


Fig. 20. Temperature at 90 minutes at the coupling reinforcement at different joint depths based on results of analyses.

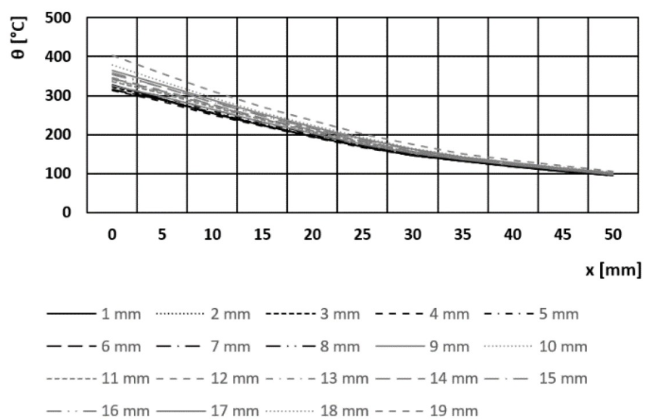


Fig. 21. Temperature at 90 minutes at the coupling reinforcement at differentjoint widths based on results of analyses.

After determining the temperature at different heights in the floor, the structural reliability could be determined.
These analyses show that the joint between two precast composite plates is not causing an additional risk for the safety of the structure when exposed to fire.

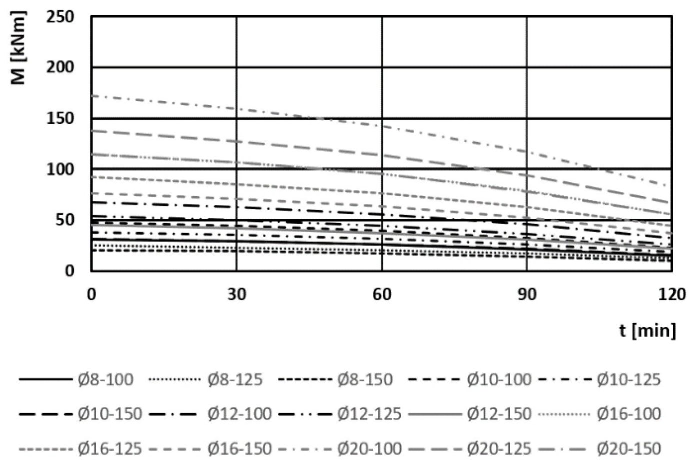


Fig. 26. Decrease moment capacity floor at the location of the coupling reinforcement based on results from analyses.

Fire resilience of cross laminated timber constructions in residential buildings

Andrès Berdugo Calderon (PT Torino)

This research contains an experimental investigation of about self-extinguishment of cross laminated timber (CLT) based on the impact of shifting radiation heat fluxes (Rfx). Initially, the behaviour of four CLT samples, made with two different types of adhesives, Polyurethane (PU) and Melamine (ME), were tested under the same initial condition of 25 kW/m^2 generated by a propane powered radiant panel for up to 120 minutes. These initial samples worked as a control reference to measure the delamination process expected to occur in the engineered timber material.

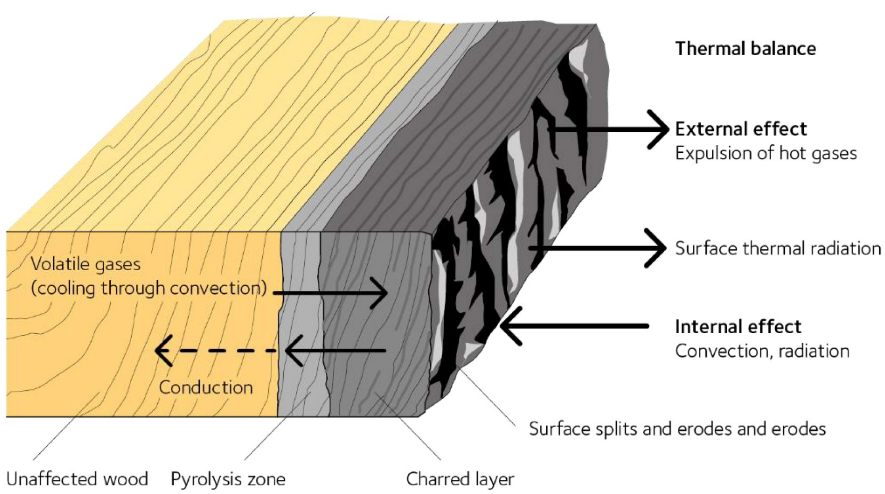


Figure 9. The phenomenon of the charring process. (Gustafsson, 2019).

The second series of experiments, tested three more samples of each adhesive type, starting with the same initial setting of 25 kW/m^2. After 30 minutes, the radiation flux was decreased to three different scenarios: 15

kW/m², 10 kW/m² and 5 kW/m² for up to 60 minutes. Glue layer temperature, front temperature and mass loss rate data were recorded during the experiments. Self-extinguishment could lead to the improvement of the probabilistic lifespan of a building (lower failure probabilities that provide higher reliability) and thus, lay out a fire resilience feature of CLT constructions, linking its usage to a sustainable development.

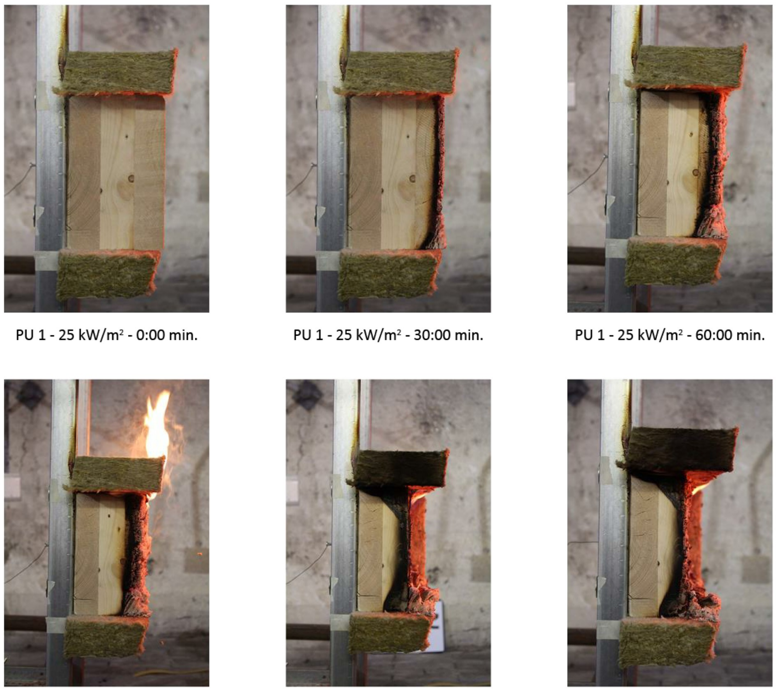


Figure 40. Time-lapse PU 1. 25 kW/m² for 120 min. Re-ignition at minute 76.

In the experiments the samples continue to burn, starting with a flaming combustion that turned after some time in a smouldering combustion. Self-extinguishment did not occur.

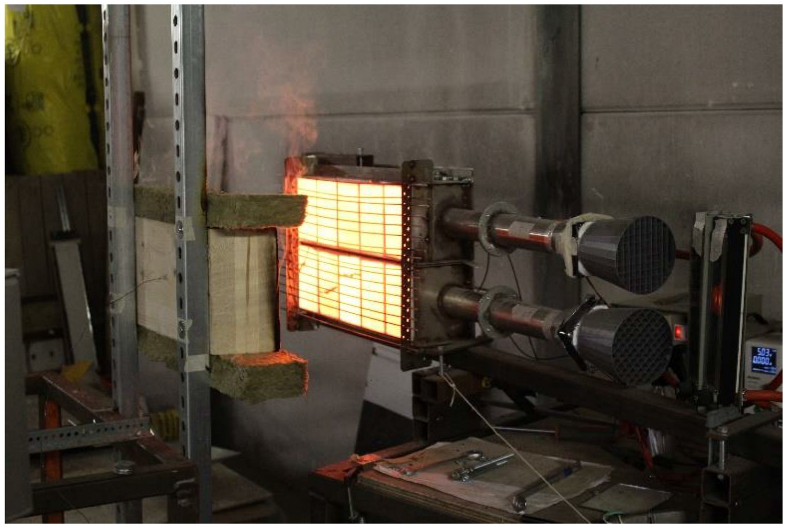


Figure 39. Testing on side B. PU 2 - 21/12/2021.

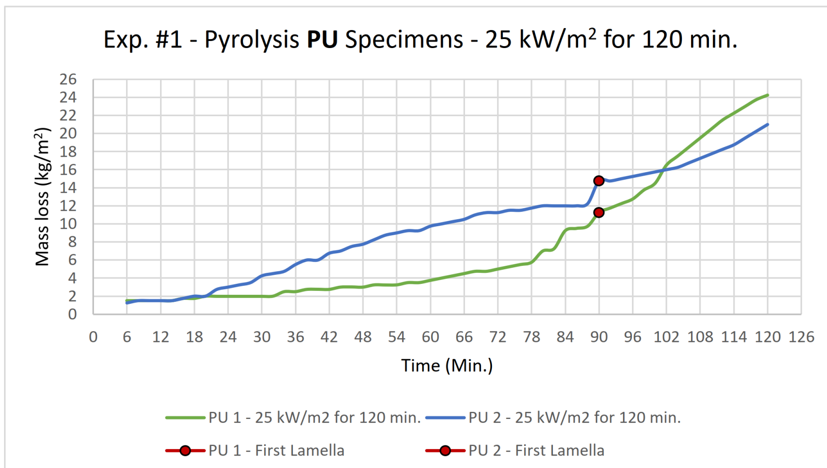


Figure 70. Mass loss per unit surface area comparative graph for PU specimens - Experiments #1.

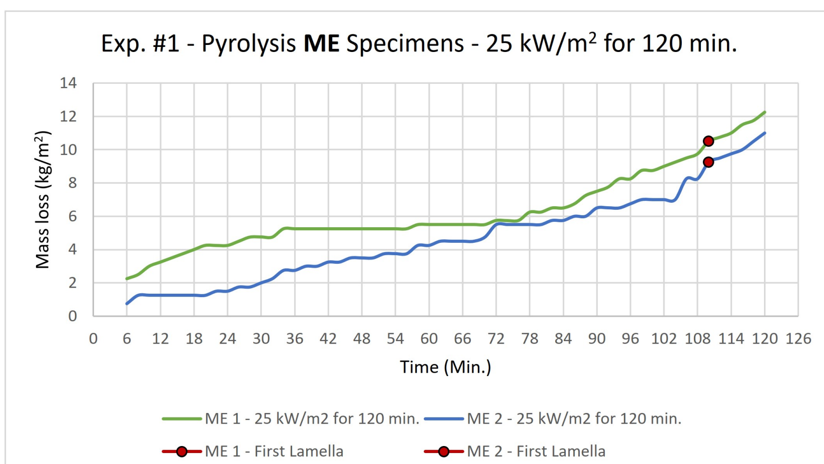


Figure 72. Mass loss per unit surface area comparative graph for ME specimens - Experiments #1.

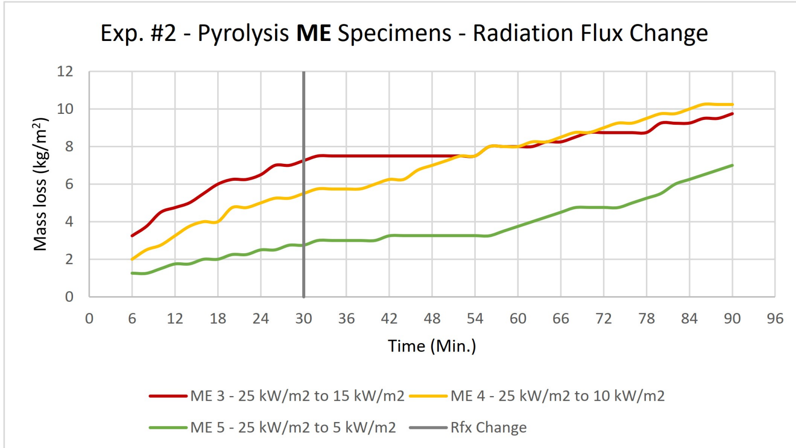


Figure 76. Mass loss per unit surface area comparative graph for ME specimens - Experiments #2.

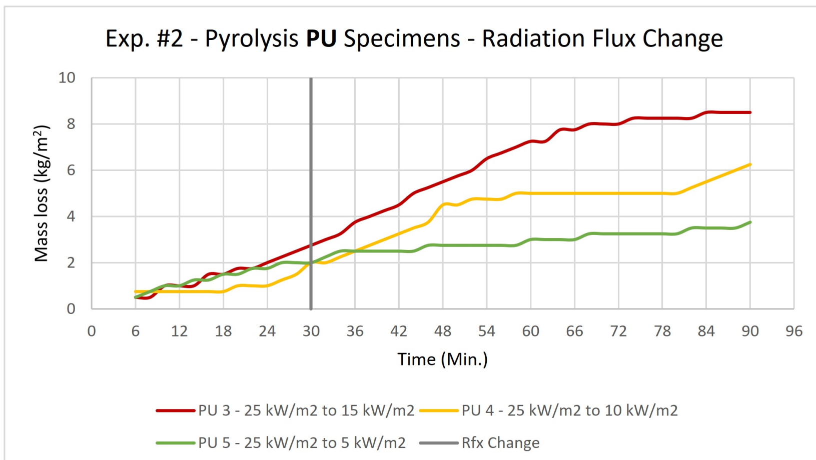


Figure 74. Mass loss per unit surface area comparative graph for PU specimens - Experiments #2.

Quantitative assessment for fire safety of supertall residential buildings with a probabilistic analysis

Joost Dumas

Low-rise buildings below 70 meters and tall buildings between 70 to 200 meters are common in the Netherlands, super-tall buildings however are not. Regulation for super-tall buildings have not yet been written in the Netherlands. Regulations for tall buildings between 70 to 200 meters has been developed based on a probabilistic approach, related tot the Dutch Building Code.

Table 3-3. Tolerability of risk [41].

Category	Probability
Maximum tolerable risk to individual member of the public	10^{-4} probability of death per year
General acceptable risk to individual member of the public	10^{-6} probability of death per year
Individual risk from fires only	
(1) At home or sleeping	1.5 * 10^{-5} per individual per year
(2) Elsewhere	1.5 * 10^{-6} per individual per year
Risk of multiple deaths from fires only	
(1) > 10 deaths	5 * 10^{-7} per building per year
(2) > 100 deaths	5 * 10^{-8} per building per year

The probabilistic approach for the regulations of tall buildings has been translated to measurements, which are applicable to multiple building functions.In this study the use of a quantitative assessment with a probabilistic analysis has been assessed in order to see if this method can be used to show that a super-tall building is just as safe as a low-rise building. With a literature study, simulations have been performed in order to assess the level of fire safety of a low-rise reference building and the level of fire safety of a super-tall building.

Numerical simulations of the low-rise residential reference building and the super-tall residential building have been performed with multizone-models: OZone, developed by Arcelormittal and the Universite de Liege and Consolidated Fire and Smoke Transport Model (CFAST), developed by NIST. A natural fire concept has been used in both simulations in order to assess the fire safety of the risk subsystems as used in the Dutch Building Code. By performing simulations of a low-rise reference building, the base level of fire safety expressed in cumulative failure probabilities, can be determined. These probabilities are the reference values, which the results of the simulations of the super-tall building need to comply with.

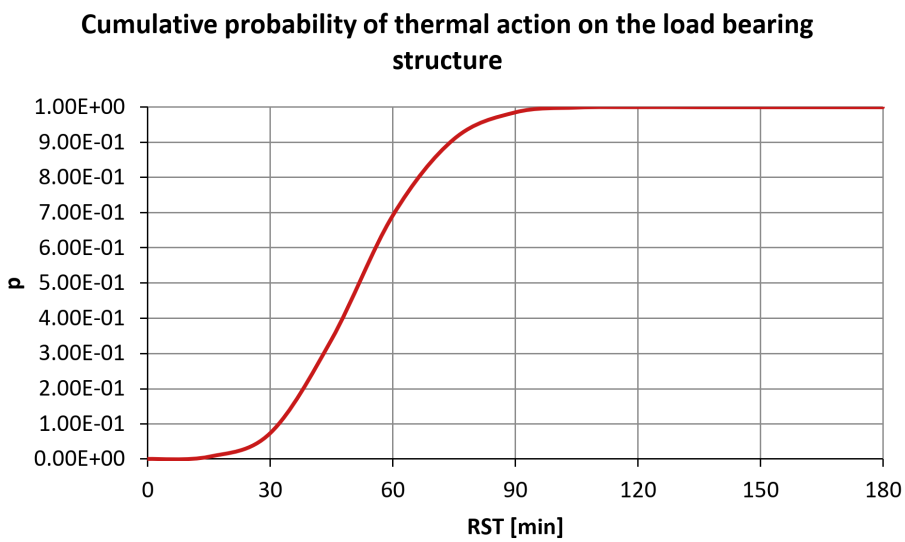


Figure 5-10. Cumulative probability of the thermal action on the load bearing structure.

The low-rise residential reference building study show that a probabilistic analysis based on a natural fire concept for buildings designed according to consequence class CC2, results in the same requirements for fire safety as set in the Dutch National Building code. The results also show that the evacuation routes can be safely used during the evacuation time and that the attack routes can be used during the fire scenario.

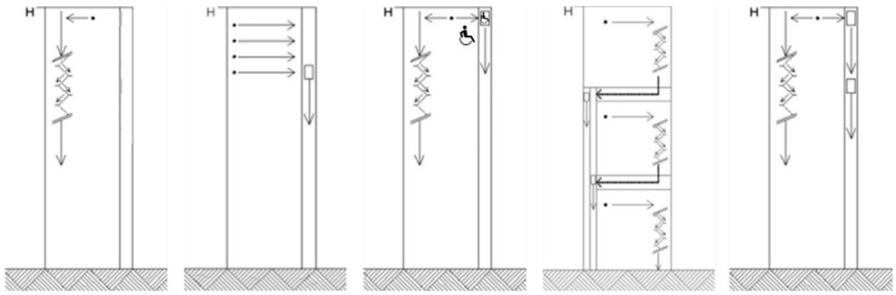


Figure 3-3. evacuation concepts of the NTA 4614-2, from left to right: 0, 1, 2, 3 and 4 [60].

Results of the super-tall residential building show that a probabilistic analysis based on a natural fire concept for building with consequence class CC3 results in an improvement of the fire resistance of the structural elements from 120 minutes to 135 minutes and that the fire resistance of the compartmentation does not have to be improved. The results also show that the application of a sprinkler system does not affect the ASET but it does affect the RST of the separation constructions in a positive way. The application of a pressurization system in the stairway lobbies does affect the ASET in the escape routes. The results also show that a full evacuation concept using stairs only can be use in a super-tall residential building when a suppression system and a pressurization system are installed. However the results also show that a full evacuation using stairs only is not the most suitable evacuation concept, because the RSET is longer than the fire scenario.

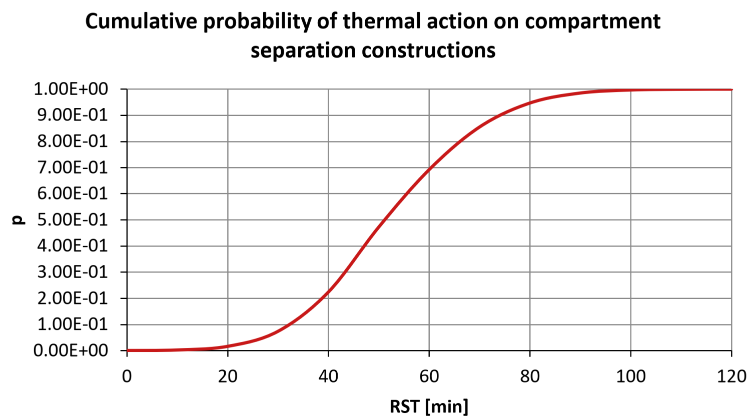


Figure 5-6. Cumulative probability of thermal action on compartment separation constructions.

The fire safety levels of both a low-rise building and a super-tall building are project specific because a performance based approach is always project specific. For other buildings (low-rise or high-rise) with other layouts or other functions the fire safety level may be different.

Although the fire safety level of buildings is project specific, a quantitative assessment with a probabilistic analysis can be used in fire safety engineering in order to assess the fire safety level of super-tall buildings so that the fire safety level of the super-tall buildings is at least the same as for low-rise buildings with the same building function(s).

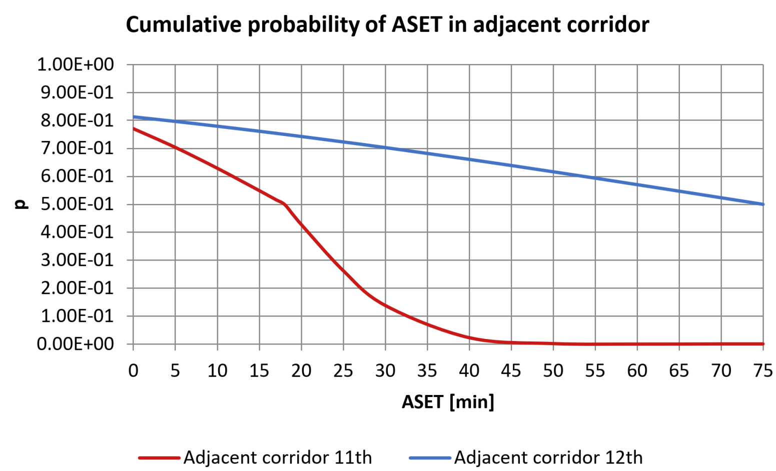


Figure 5-11. Cumulative probability of ASET in the adjacent corridor.

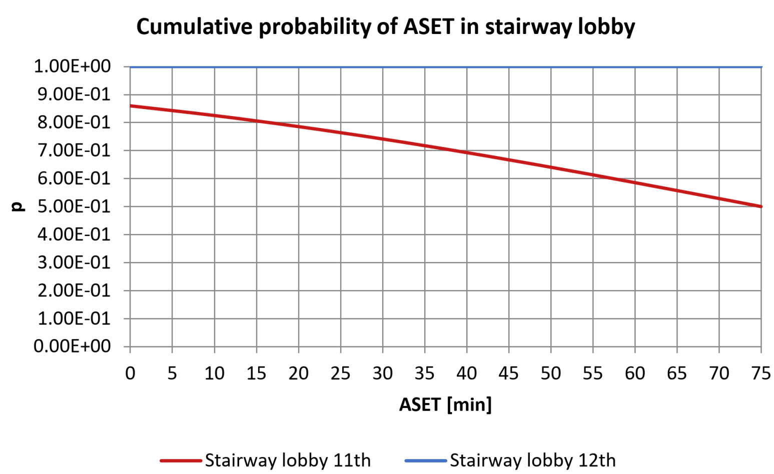


Figure 5-12. Cumulative probability of ASET in stairway lobby.

Multi-storey residential buildings in the event of fire: relief of the fire-induced overpressure without causing smoke spread via the ventilation system

Nora Kuiper

Today, more and more attention is paid to decreasing the energy demand of buildings. To reduce the energy demand for heating and cooling, buildings are increasingly airtight and heat recovery ventilation (HRV) units are implemented in the mechanical ventilation systems. Two challenges, with regards to the fire safety in buildings, arise from this modern way of building: (1) in case of fire an overpressure occurs in the fire compartment, which might potentially hinders safe evacuation of occupants; (2) smoke spread to other compartments is observed consecutive to the overpressure in the fire compartment. This is of relevance for all buildings, but particularly for residential complexes as they consist of relatively small fire compartments.

Figure 6-1. Impression of De Cavaliere, Helmond

In this graduation project, the essence was to explore the potential solutions to relax the fire-induced pressure via the ventilation system, without increasing smoke spread to other apartments. Two studies were performed, developing a decoupled modeling approach with the zone model CFAST and the multizone model CONTAM. This link was made to overcome the limitations of both modeling software. The potential of this modeling approach was tested in a calibration study based on a reference case, and proven as the pressure development was adequately predicted, especially during the growth phase of the fire, and smoke spread to other apartments was revealed.

Table 6-5. Input characteristics for the CFAST models

		3.04	3.06	4.05
Compartment width	m	8.15	8.15	8.15
Compartment length	m	11.85	11.85	11.85
Compartment height	m	2.6	2.6	2.6
Wall vent height	m	2.6	2.6	2.6
Wall vent width	m	0.0024	0.0037	0.0024
Ceiling vent area	m^2	-	-	0.0078

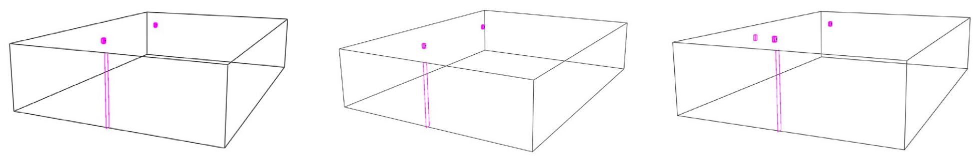


Figure 6-6. Model geometry of apartments 3.04 (left), 3.06 (middle), and 4.05 (right), visualized in SmokeView

The methodology and the findings of the calibration study were used as a reference for the case study, to predict the pressure development and the smoke spread for the case study building The case study showed that implementing a bypass would not significantly reduce the overpressure in the fire apartment. Smoke spread was found primarily via the inlet system, and therefore, additional simulations on implementing fire dampers were performed. The fire dampers limited smoke spread to apartments connected via the collective ducts. However, as a result of the increase in pressure, it increased smoke spread via the interior separation structure.

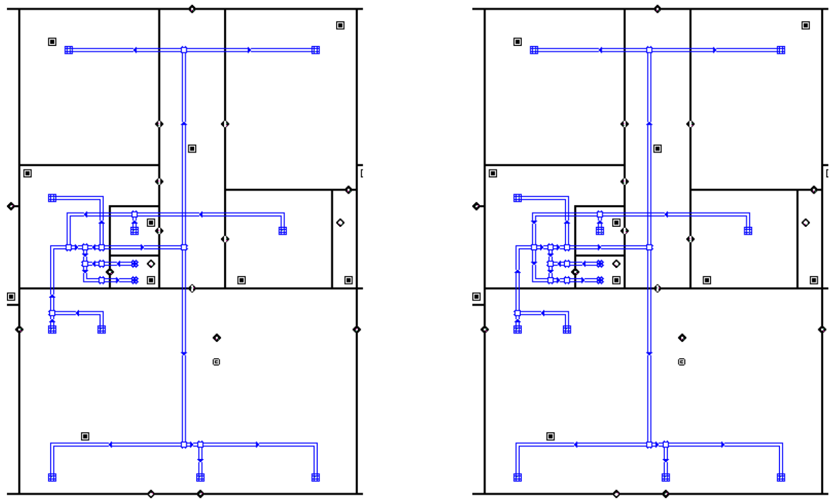


Figure 6-8. CONTAM geometry without (left) and with (right) modelled bypass

Based on the two studies and multiple tests of different variants of the ventilation configuration, it was concluded that there is no solution satisfying both problem statements as of yet. Therefore, it is recommended to explore solutions in the building structure instead.

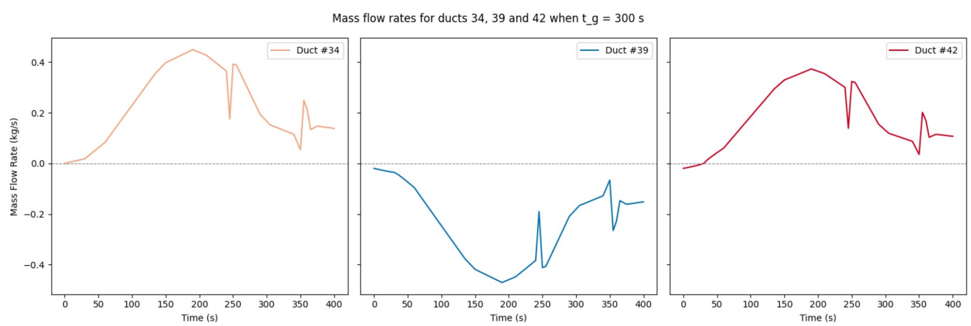


Figure 6-13. Mass flow rates for ducts 34, 39 and 42 when t_g = 300 s

Sponsors of Stichting Fellowship FSE WO²

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At the moment of publication these companies and organizations are in alphabetic order:

Acuro

Is my housing or design fire safe and does it comply with applicable regulations? The answer to this question is often not immediately apparent. A world of laws and regulations reveals itself. We advise our clients effectively, for both existing and new housing.

Our working method and approach to the fire safety issue leads to the most appropriate solution that complies with the regulations and also provides a fire-safe situation that meets the wishes of our clients. In doing so, we also look with them at aspects such as limiting material damage and ensuring business continuity. In other words, we provide smart and responsible fire safety solutions!

Website
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BOUWEN MET STAAL

BOUWEN MET STAAL is active in promotion, advice and information, knowledge transfer and research for the use of steel in construction. The activities are mainly tailored to the application areas of industrial construction, utility construction, residential construction and infrastructure. Its activities are primarily tailored to the application areas of industrial construction, utility construction, residential construction and infrastructure. Activities include:

- training courses for structural engineers, structural draftsmen and steel draftsmen;
- courses and seminars on application aspects such as detailing, building physics, fire safety and regulations;
- tools for the design, dimensioning and detailing of steel structures;
- publications (books, reports, brochures, digital productions) for practice and education;
- bi-monthly magazine Building with Steel;
- Biennial National Steel Award;
- Annual National Steel Construction Day.

BOUWEN MET STAAL also provides an association for all stakeholders and those interested in steel in construction.
The association has some 2,500 personal and corporate members and some 20 Gold Members. For members, the association acts as a platform for sharing new professional knowledge and experience. For this exchange, the association organizes, among other things:

- evening sessions at member companies;
- symposium For and by steel constructors;
- StudentenSTAALprijs, the annual award for graduation work with steel at technical universities and colleges of technology.

Website:
http://www.bouwenmetstaal.nl
http://www.brandveiligmetstaal.nl

Federation Safe Netherlands

Federatie Veilig Nederland Business association Federatie Veilig Nederland is the advocate for technical (fire) safety in the Netherlands.

The Federatie Veilig Nederland association is a professional entrepreneurs' association with approximately 150 members, all specialized companies with solutions for many fire safety and security issues. The association represents the general, economic, commercial and strategic interests of its members.
Investing in education and training is a spearhead of the business association. In particular, the 'Verenigde Sprinkler Industrie' (VSI) section promotes Fire Safety Engineering courses so that students develop knowledge in the field of active extinguishing systems.

Federation Safe Netherlands stands for quality companies, clear language, a strong organization and added value for its members. Expert support, service and advocacy are paramount.

Website:
https://federatieveilignederland.nl/

NVPU

The 'Nederlandse Vereniging van Polyurethaan hard foam-fabrikanten' (NVPU), strives for a healthy and balanced business climate in the Netherlands and Europe for its members active in the production and processing of polyurethane (PUR) and polyisocyanurate (PIR) hard foam used as thermal insulation in construction.

NVPU aims to represent the interests of its members. However diverse and different the members are, the NVPU aims to formulate a common vision on relevant issues in order to decisively represent the industry. Thus, NVPU strives to create a technical, economic and legal environment in which healthy business operations are made possible for all its members.

In doing so, the NVPU focuses on:
1. Monitoring relevant developments within the industry.
2. Informing members about these developments.
3. Provide a platform for consultation with members.
4. Binding the members.
5. Promote the association position in a broad sense.
6. Inform policy makers and decision makers.

Website
www.nvpu.nl

OCB

OCB offers general and vocational training in the field of fire safety. Modern training focuses on the development of skills rather than the transfer of knowledge. All courses have been transformed to meet this need.
We have our training facilities, but the courses can often also be given in-company. The teachers are all still active as specialists in their field and bring 'practice' to the classroom. Because of the modular structure of our training courses, we are quickly able to respond to a specific demand by exchanging modules. For more information on training courses and opportunities, please visit our website.

Website
www.hetocb.nl

Rockwool

ROCKWOOL® is the international market leader in stone wool insulation. ROCKWOOL stone wool insulation is fire safe, protects buildings from heat loss and reduces energy consumption and CO_2 emissions.

In addition, ROCKWOOL stone wool insulation contributes to the sustainable and lifelong improvement of overall building efficiency by increasing fire safety and acoustic comfort.

ROCKWOOL is part of the ROCKWOOL Group: a trusted partner in creating efficient and aesthetic solutions that protect buildings from the environment and the environment from the impact of buildings. The ROCKWOOL Group supplies products and services worldwide that enable the creation of aesthetically pleasing buildings that provide comfortable living, working and living conditions.

Website
www.rockwool.com

Stybenex

The association Stybenex represents the interests of Dutch EPS producers and their products. Stybenex consists of 5 members who together represent about 95% of the Dutch market for EPS construction and packaging products.

EPS is one of the most versatile products in construction. It has a lifespan of more than 75 years without losing its thermal and mechanical properties. Its properties are ideal as an insulation material, but also as a light fill material for Earth, Road and Hydraulic Engineering.

Stybenex informs the market about the good properties of EPS in the light of Circular Economy and Sustainability. Stybenex has been actively involved in collection and recycling projects since 1972. EPS is the only

insulation material that can be used directly and without additional processes via recycling into new EPS products.
Stybenex is active and initiates numerous consultations and committees where EPS products and applications (may) play a role. To this end, contacts are maintained with various research agencies and other industries in the construction industry in the field of energy savings, environmental performance, fire safety and the circular economy.
Stybenex is committed to an objective assessment of EPS products in application at construction and building level. In accordance with the Buildings Decree, Stybenex uses performance principles at integral level in the application and not on the basis of the bare material.
Stybenex is a member of EUMEPS, the European umbrella organization for EPS. Stybenex is also a member of the Dutch Insulation Industry (NII) and the Dutch Rubber and Plastic Industry (NRK).
Through the NII, Stybenex is also active in the Dutch Association of Producers in the Building Supply Industry (NVTB) and active in numerous national and international committees on standardization (NEN, CEN) and certification (SGS Intron, KIWA, SGK IKOB, Insula).

Website
www.stybenex.nl

VVBA

The association of fire safety advisors VVBA was founded in 2002 with the aim of setting a standard for the own responsibility that fire safety advisors have to take. After all, fire safety consultancy is not just about the approval of reviewing bodies. Fire safety advice should lead to actual safety. So call the VVBA the "fire safety conscience" of consulting firms.

For standard consultancy work, such as interpretation of fire safety regulations, dimensioning of smoke and heat extraction systems (RWA according to NEN 6093), fire spread calculations (WBO according to NEN 6068), model controllability of fire (large fire compartments) and sprinkler protection concept, the VVBA has drawn up technical guidelines. This increases the uniformity and quality of the consultancy work.

The association also provides a consultation platform for its members when it comes to advice outside the standard activities and developments in the field of regulations and fire safety engineering. Through this consultation platform, influence can also be exerted on new developments; the VVBA is represented as an industry association in various committees and working groups.

In particular, the VVBA advocates alignment between fire safety regulations and Fire Safety Engineering. This alignment is necessary to apply Fire Safety Engineering in project-specific (customized) solutions. Currently, this often leads to bottlenecks because the fire safety regulations do not provide sufficient guidance for testing customized solutions with Fire Safety Engineering.

Finally, the VVBA advocates information exchange with testing and advisory parties in the field of fire safety. The annual VVBA lecture afternoon is an example of this. But support is also given to the post-HBO courses Fire Safety Engineering (Stichting Kennisoverdracht Bouwfysica and Hogeschool Windesheim Zwolle), the HBO course Fire Safety Engineering BSc (Hanzehogeschool Groningen) and (guest) lectures in architectural education at various colleges and universities. Read on the website who the members of the VVBA are.

Website
www.vvba.nl

Inhoudsopgave