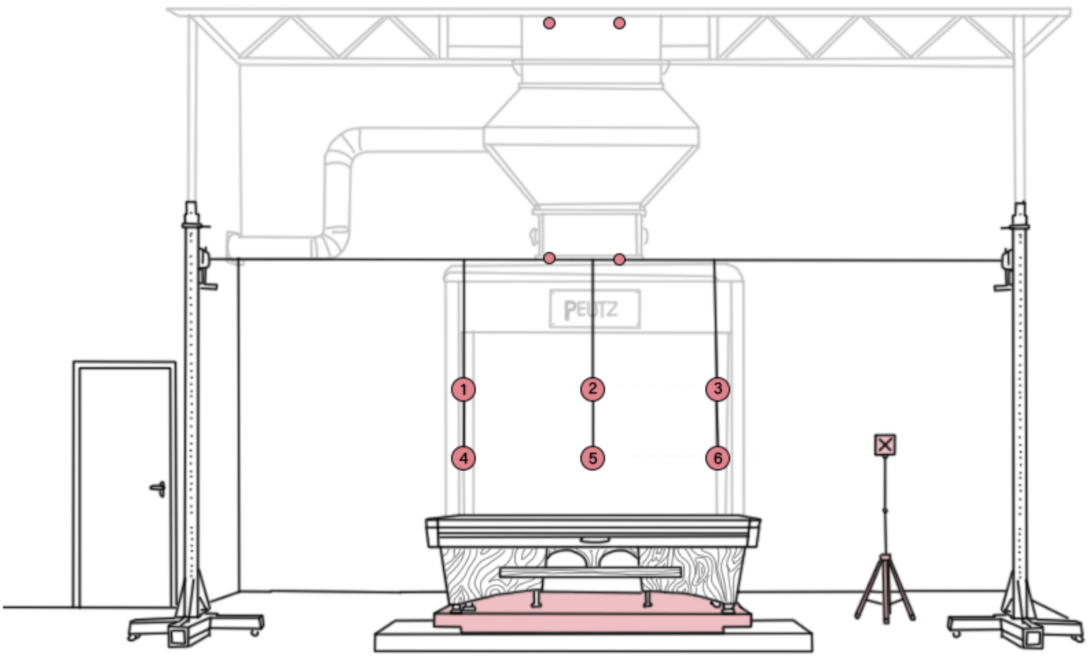
Fire Loads in Escape Routes

Ensuring Equivalent Fire Safety in Senior and Residential Housing



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Ensuring Equivalent Fire Safety in Senior and Residential Housing

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Building Physics and Services (BPS)

Unit Building Services and Fire Safety Engineering

The Master's Project has been carried out in accordance

with the rules of the TU/e Code of Scientific Integrity.

Abstract

The presence of combustible objects within escape routes is discouraged by Dutch fire safety regulations, as such objects may contribute to fire growth, smoke production, and reduced evacuation safety. However, in residential care facilities, communal spaces often contain large items of furniture that improve the quality of life of the residents. One example is the presence of billiard tables within atria. This research investigates to what extent a billiard table located within a residential escape route affects evacuation safety and under which conditions its presence can be justified as providing an equivalent level of fire safety according to Dutch fire safety principles.

The study was conducted using a combination of fire experiments, fire and smoke modelling, and evacuation analysis. Two billiard tables with different constructions were tested with controlled ignition experiments to determine their mass loss rate (MLR), heat release rate (HRR), thermal behavior, and smoke production. The experimental results were used as input for a series of CFAST fire simulations representing the atrium of the elderly home. In addition, Pathfinder evacuation modeling was performed to compare the Available Safe Egress Time (ASET) with the Required Safe Egress Time (RSET) of elderly and mobility-impaired occupants. A parametric analysis was conducted to see the influence of building geometry on fire safety performance.

The experiments showed that neither billiard tables developed into sustained flaming. Both specimens stayed in a localized smoldering state, resulting in minimal mass loss, negligible temperature increases, and heat release rates below 4kW. The simulation results showed that thermal tenability limits were never reached and that visibility remained well above accepted safety thresholds, even under conservative assumptions regarding smoke production. As a result, the calculated ASET was much greater than the RSET for all cases.

The research concludes that a traditional billiard table has a lower fire hazard than commonly assumed. Within large-volume residential atria the presence of a billiard table can be justified as providing an equivalent level of fire safety, if performance-based analyses show sufficient tenability conditions and sufficient safety margins between ASET and RSET. Furthermore, the findings indicate that a Stay-in-Place strategy may be a safer and more adequate response than full evacuation in the event of localized billiard table fire within a residential care environment.

Keywords: Fire Safety Engineering, Performance-Based Design, Billiard Table Fire, Smoldering Combustion, CFAST, Pathfinder, ASET/RSET, Stay-in-Place, Senior Housing, Equivalent Fire Safety.

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List of Abbreviations

Abbreviation	Definition
ACM	Asbestos-Containing Materials
ASET	Available Safe Egress Time
Bbl	Besluit Bouwwerken Leefomgeving (Dutch Building Decree)
BBRAD	Brandskydd I byggnader – Allmanna rad (Swedish Building Code fire safety regulations/benchmarks)
BPS	Building Physics and Services
CFAST	Consolidated Model of Fire Growth and Smoke Transport
CFD	Computational Fluid Dynamics
CO	Carbon Monoxide
CO_2	Carbon Dioxide
FDS	Fire Dynamics Simulator
FED	Fractional Effective Dose
FEDthermal	Fractional Effective Dose for Thermal Radiation and Convective Heat Exposure
FEDtoxic	Fractional Effective Dose for Toxic Gases
FSE	Fire Safety Engineering
HCN	Hydrogen Cyanide
HRR	Heat Release Rate
ISO	International Organization for Standardization
MDF	Medium-Density Fiberboard
MLR	Mass Loss Rate
NIST	National Institute of Standards and Technology
O_2	Oxygen
RSET	Required Safe Egress Time
RWA/SHEV	Rook-en Warmtevervoer / Smoke and Heat Exhaust Ventilation (System)
SFPE	Society of Fire Protection Engineers
TU/e	Eindhoven University of Technology
VRZHZ	Veiligheidsregio Zuid-Holland Zuid

Terminology

Equivalent Safety (Gelijkwaardigheid): A regulatory mechanism under the Omgevingswet allowing deviations from strict prescriptive requirements, provided it is scientifically proven that the alternative solution guarantees an equal level of safety.

Performance-Based Design: An engineering design methodology that replaces rigid codes with quantitative analyses of safety outcomes, usually evaluated by ensuring the available safe escape window exceeds the required time (ASET>RSET).

Stay-in-Place Strategy: A fire safety response where vulnerable, non-self reliant, or immovable residents stay safely within their fire-rated compartments rather than executing full evacuations across active localized fire zones.

Tenability Limits: Threshold criteria (such as minimum visibility distances, maximum radiant heat fluxes, and maximum accumulated toxic gas fractions) inside a space, below which conditions remain safe for humans.

Smoldering Combustion: A slow, low-temperature, flameless form of combustion characteristic of high-density materials, it causes minimal energy output and mass loss but produces persistent, uniformly distributed smoke.

Extra-Protected Escape Routes: Shared corridors and egress paths within care-dependent residential functions that prescriptively ban combustible fire loads to protect occupants who suffer from compromised independent evacuation capabilities.

Thermal Inertia: A compound physical property of heavier structural parts (such as a dense hardwood timber sub-frame) that dictates their resistance to temperature rise, as a result preventing fire growth and self-sustaining ignition.

Heat Sink: An element (specifically the massive slate playing bed within a billiard table assembly) capable of continuously conducting and storing thermal energy and suppressing surface temperatures below critical ignition limits.

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1 Introduction

1.1 Problem Statement

In the Netherlands, fire safety in the built environment is mostly lead by the Besluit bouwwerken leefomgeving (Bbl). A fundamental principle of the Bbl regarding escape routes is the limitation of fire loads to make sure that these paths remain usable for the duration of an evacuation. Specifically, for residential functions including care component, like senior housing, prescriptive regulations completely prohibit combustible materials in shared escape routes. This measure is applied to prevent smoke development and heat radiation from blocking the only available way for people, who often have reduced self-reliance.

However, this prescriptive no tolerance approach often conflicts with the social and functional requirements of elderly housing nowadays. Large atriums (see Appendix B for floorplans and sections of the senior housing) (see Appendix C for picture of the atrium) and corridors are regularly designed as small central social hubs with furniture, such as billiard tables. These social spots play an important role in the residents' quality of life and mental well-being. This creates a tension between the social necessity of a furnished environment and the set requirements of prescriptive fire codes.

Currently, fire safety specialists and Safety Regions (Veiligheidsregio's) lack a standardized, scientifically supported methodology to allow such items under the principle of Equivalent Safety (Gelijkwaardigheid).

While the Handreking Brandveilig Gebruik van Vluchtroutes gives a framework for assessing fire loads, it relies mostly on fire load estimates and simplified fire curves. It does not take into account the exact material composition of billiard tables, consisting out of hardwood frames, vulcanized rubber cushions, and wool-synthetic blends, nor does it take into account the specific Stay-in-Place versus Evacuation strategies required for vulnerable people. As a result, there is a significant knowledge gap concerning the actual Heat Release Rate (HRR) and smoke production capabilities of these objects, which lead to irregular application of the regulations and likely unnecessary restrictions on resident freedom.

Figure 1: Office of the VRZHZ in Dordrecht, Leerpark (Google Maps, n.d.)

1.2 Research Objective

The main objective of this master project is to quantify the fire risk of a billiard table, that is located in a residential escape route and to determine the conditions under which it can be left at it's intended place, while providing equivalent safety.

In this project, a justified presence is defined as a scenario where the safety margin (ASET – RSET) stays positive and tenability limits are not exceeded, even under conservative, worst-case conditions. To ensure the findings are practical, the research uses a 10.79 meter high atrium in a building as a baseline, a typology frequently encountered by the Safety Region.

In order to achieve this in the research the following aims will be set:

1. Characterizing the object specific fire behavior (HRR, smoke, and toxicity) of a traditional billiard table through experimental validation.
2. Develop a performance-based framework that combines the Swedish Building Code (BBRAD) benchmarks for impaired mobility into Dutch safety contexts.
3. Take into account the impact of different type of tables and material setups on the Available Safe Egress Time (ASET) and Required Safe Egress Time (RSET) using simulations.

1.3 Research Questions

The main research question is:

To what extent does a billiard table placed in a residential escape route affect evacuation safety, and under which conditions can its presence be justified as providing equivalent fire safety according to Dutch building regulations?

To answer this, the following sub-questions are addressed:

What fire safety performance criteria (e.g. radiation exposure, smoke layer height, visibility) are relevant for assessing evacuation safety in senior housing?

What are the fire characteristics (HRR, mass loss rate, soot yield) of a traditional billiard table, and how do material variations (e.g. frame type) influence these?

How does the presence of billiard table fire affect the ASET in a typical atrium building compared to the RSET of vulnerable occupants?

Can a Stay-in-Place strategy provide a higher level of safety than total evacuation in the event of a localized furniture fire in an escape route?

1.4 Research Relevance

This research is relevant as it moves away from the generalized concept of fire load density (MJ/m^2) assumptions towards a more object specific fire engineering. By using a consolidated Model of Fire and Smoke Transport (CFAST) and occupant movement modeling (Pathfinder), it supports the field of Performance Based Design.

Both socially and legally, the project is relevant for the Veiligheidsregio Zuid-Holland Zuid (VRZHZ) and to other Veiligheidsregios in the Netherlands who might face the same problem.

It gives a technical ground based on which informed decisions can be made, that balance fire safety with the liveliness of senior care facilities and residential complexes. Furthermore, by comparing the Dutch safety levels against the Swedish BBRAD, this research uses a new approach on safety factors for impaired mobility in the Dutch regulatory framework.

1.5 Research Methodology

Literature Study: Setting the safety thresholds (ASET/RSET) and identifying the thermal properties of billiard table components (Hardwood, Rubber, Felt).

Experimental Phase: Conducting laboratory experiments (in collaboration with Peutz b.v.) to determine the ignition probability and initial fire growth rates of the tables

Numerical Simulation: Running a parametric analysis in CFAST to model smoke spread in an atrium and using Pathfinder to simulate evacuation of 20+ vulnerable residents under various staffing scenarios.

Synthesis and Validation: Comparing simulation results with the Equivalent Safety requirements of the Bbl and the tenability limits of the Swedish code to formulate a final recommendation.

1.6 Research Limitations

The research takes into account traditional hardwood billiard tables, so the results may differ for lightweight MDF or tournament grade plastic-composite tables

The human behavior in Pathfinder is based on the standardized walking speeds for the elderly (2/3 reduction), psychological factors like fire induced panic are not explicitly modeled but are addressed through conservative pre-movement time delays.

1.7 Structure of Report

Chapter 2: lays the theoretical background, focusing on the Dutch Bbl and the Swedish BBRAD benchmarks.

Chapter 3: details the material characteristics of the billiard table fuel package and the historical significance of carambole billiard tables in the Dutch culture

Chapter 4: describes the experimental setup and mass loss rate calculation method. Furthermore it deals with the methodology, detailing the input parameters for both the CFAST fire simulations and Pathfinder evacuation models.

Chapter 5: presents the results of the physical fire tests that are conducted at the Peutz b.v. Laboratory in Haps

Chapter 6: details the results of the numerical simulations generated by CFAST and Pathfinder

Chapter 7: provides a critical discussion and comparative analysis of the experimental and simulation results.

Chapter 8: summarizes the main conclusions of the research, delivering final design and strategy recommendations alongside possibilities for future study.

2 Regulatory and Safety Framework

The following chapter will deal with the legal and technical boundaries within which the fire risk of a billiard table is assessed. To bridge the gap between prescriptive Dutch regulations and the functional requirements of senior housing, a performance based approach is considered, which means using national (Dutch) standards and international benchmarks.

2.1 The Dutch Building Code (Bbl)

In the Netherlands, the Besluit bouwwerken leefomgeving (Bbl) serves as the main legal document for fire safety. For buildings that have a residential function including the ones with a care component (woonfunctie met zorg), the Bbl is quite strict regarding escape routes.

With the prescriptive rules in fact, shared escape routes (extra-protected escape routes) must be virtually free of any kind of combustible materials to prevent smoke from blocking the only available path for susceptible residents. However, the Omgevingswet (Equivalent Safety/ Gelijkwaardigheid) allows for deviations from these prescriptive requirements. As stated in the introduction, the goal of the research is to use this article to justify the presence of the billiard table by proving that the level of safety will stay at least equal to that aimed by the code.

2.1.1 The Handreiking (Different from Handreiking 7.11a)

The Handreiking Brandveilig Gebruik van Vluchtroutes (Manual for Fire Safe Use of Escape Routes) [6] gives a framework for these exceptions. It supports that the acceptability of fire loads does depend on:

Spatial Geometry: Spaces with greater volumes, like atriums (e.g. the 10.79m baseline in this study)

Ventilation: The presence of natural or mechanical smoke and heat exhaust systems (S&HE)

Object Characteristics: HRR and smoke yield.

While the Handreiking gives a good idea for the methodology, it often relies on generalized furniture HRR curves. This report moves beyond these generalizations by determining object-specific data for the billiard table in Chapter 5, and by conducting experiments to get the exact HRR curves.

2.2 Performance Based Design: The ASET/RSET Concept

In order to quantify Equivalent Safety, the relationship between the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET) are used as the main performance indicators.

Safety Requirement

$$[eq.1]\ ASET > RSET$$

ASET: The time between ignition and the moment environmental conditions (tenability limits) become life-threatening.

RSET: The time required for detection, notification, pre-movement, and travel to a safe area.

2.3 Safety Criteria for Vulnerable Populations

To define the ASET, specific thresholds must be defined. Because the Dutch Bbl gives very little guidance on quantitative tenability limits for performance based design, this research will use criteria from ISO 13571 and the Swedish BBRAD [3], which are internationally recognized for assessing life safety.

2.3.1 Smoke Layer Height and Visibility

Visibility is the first criteria that is to be compromised in a furniture fire. For occupants who do not have a perfect vision or mobility, maintaining a smoke free height is crucial for orientation purposes.

Table 1: Smoke Layer Height and Visibility Tenability Limits

Criteria	Threshold (Large Spaces)	Threshold (Small Spaces)	Source
Smoke Layer Height	> 2.5 m (or 1.6 + 0.1 x H)	>2.5 m	Dutch Bbl/BBRAD
Visibility	>10 m	>5 m	Swedish BBRAD

The formula from the Swedish BBRAD (1.6+0.1 x ceiling height) [3] is especially relevant for the 10.79 meter atrium baseline in this study, as it makes sure that the smoke layer stays significantly above the heads of residents even as it cools.

2.3.2 Thermal Radiation and Temperature

For older residents, skin sensitivity and the inability to move swiftly away from a heat source make radiation limits more severe than in standard office buildings.

Radiation Limit: In this study, a limit of <1KW/m^2 is aimed for at floor level to ensure that all residents can pass a burning billiard table without suffering pain or skin burns.

> *Note:* While the Society of Fire Protection Engineers (SFPE) often cites 2.5 kW/m^2 for short exposures, the lower limit is used here to account for the slow speeds of residents.

Convective Temperature: Air temperature must remain <80°C at the breathing zone (1.6 m) to avoid respiratory tract damage.

2.3.3 Toxicity (Fractional Effective Dose)

Toxicity is measured by using the Fractional Effective Dose (FED), which takes into account the cumulative effect of Carbon Monoxide (CO), Carbon Dioxide (CO_2), and low Oxygen (O_2)

Limit: FED<0.3 (for sensitive populations)

> While FED<1.0 is the standard for healthy adults, a lower threshold of 0.3 is common to use for the elderly to provide a buffer for pre-existing respiratory or cardiovascular conditions.

2.4 Benchmarks for Impaired Mobility (Swedish BBRAD)

There is a significant gap in the Dutch Bbl, and it is the lack of specific reduction factors for walking speeds of the elderly. This research uses the Swedish BBRAD (Section 3.2.4) [3] as a reference.

Walking speed assumptions:

Standard Speed: ≈1.2-1.5 m/s

Senior/Impaired Speed: A 2/3 reduction factor is applied to take into account the reduced mobility speed of the elderly, resulting in a horizontal travel speed of 1.0 m/s for independent seniors and significantly lower for those using walkers or wheelchairs.

2.5 Summary

Table 2: Summary of the tenability limits for the Dutch Code and the Swedish Code

Category	Criteria	Threshold (Limit)	Source	Purpose
Visibility	Minimum Distance	> 10m	BBRAD	Make sure that residents can see exits in large atrium volumes.
Heat (Radiation)	Radiant Heat Flux	<1 kW/m^2	SFPE	Prevent pain/burns for slow-moving elderly near the fire.
Heat (Convection)	Air Temperature	<80°C	ISO 13571	Protect respiratory tracts during evacuation.
Smoke Height	Clear Layer Depth	>1.6+0.1xH*	BBRAD/Bbl	Keeps smoke above head level
Toxicity	Fractional Effective Dose	FED<0.3	ISO 13571	Accounting for pre-existing conditions in seniors.
Tenability (Smoke)	Maximum Gas Temperature	<200°C	ISO 13571	Prevents smoke layer from losing buoyancy and "dropping".

*H = internal height of a large volume (e.g. atrium)

3 Methodology

This chapter deals with the multi tiered methodology created to evaluate the fire risks connected with introducing localized combustible furniture loads into evacuation corridors. To go from generalized fire densities towards an objective performance based fire safety engineering design, this framework combines experimental laboratory testing with deterministic and stochastic numerical simulations models.

The methodology is made in a way to structurally resolve the conflict between the strict prescriptive mandates of the Dutch Bbl and the functional requirements of modern residential and senior housing spaces. By calculating the fire curves from the controlled laboratory experiments and inputting them into a multi zone simulation, a quantitative validation of the Equivalent Safety, so that the safety margin can be proven.

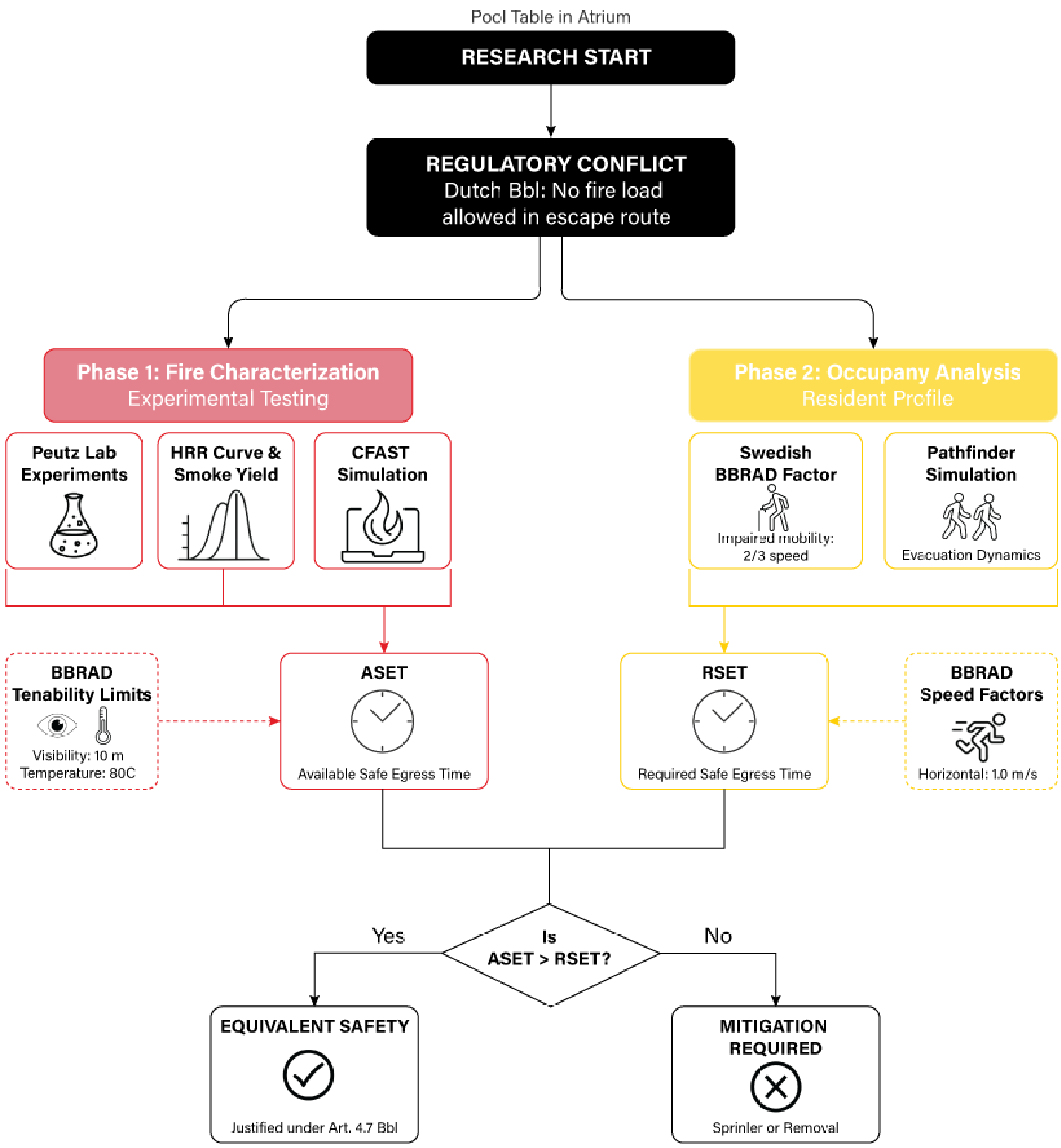

Figure 2: Methodology Diagram

3.1 Experimental Plan – Object Specific Fire Characterization

3.1.1 Objectives and Performance Indicators

Full-scale fire testing was executed at the accredited Fire Safety Laboratory of the Peutz b.v. located in Haps, the Netherlands. The laboratory works with strict international standards for fire performance and testing metrics, using specialized receiver hoods, gas analysis instruments and data logging environments.

Using this testing space will allow for an analysis of the ignition mechanism, localized fire, flame and smoke propagation across the composite table assemblies, and vertical temperature profiles under controlled settings.

With the experiments the goal is to provide realistic data for subsequent CFAST simulations. The following parameters are taken into account:

Heat Release Rate (HRR): Looking at the peak energy output and the growth coefficient.

Smoke and Soot Yield: Identifying conservative values for smoke and soot production.

Mass Loss Rate (MLR): Correlating fuel consumption with energy release.

Time to First Smoke: Determining the detection window for vulnerable residents.

Note: For more information on the construction of the billiard tables and for the full literature review more information can be found in Appendix A.

3.1.2. Billiard Table Requirements and Selection

To make sure that findings are conservative and representative at the same time, traditional carambola (pocketless) billiard tables manufactured with hardwood sub-frames were selected as the main test specimens. To meet health and safety protocols set by the testing laboratory, all tables were verified to have been manufactured post-1995. This parameter strictly excludes the risk of encountering toxic Asbestos-Containing Materials (ACM), in the past usually integrated into older slate structural adhesives, frame core, or as insulation backing.

The structure and mass composition properties of the two tested tables varied significantly. This required specific adaptations in the physical data collection:

Table 1: constructed with a dense hardwood frame, the physical mass of this table needed a two-step weighing procedure to precisely register its total load. The total dry weight was logged at 1054.79 kg (consisting of two discrete components of 513.49 kg and 541.30 kg.

Figure 3:Pictures of Table specimen 1 (left picture) and Table 2 (right picture)

Table 2: this table has a smaller spatial geometry and lower volume of timber, therefore the total mass of this object fell within the optimal operating threshold of the laboratory's continuous weighing setup (maximum precise range is approximately 1000 kg). This feature allowed for the continuous logging of real time mass loss during the active burning phase.

Before the ignition tests, all tables were stored inside the laboratory hangar under similar environmental conditions, maintained at a stable ambient temperature of around 14°C and a relative humidity threshold of 50%. These conditions are slightly different than that of an elderly home or residential gathering place, but still ensured that the moisture content of the timber sub-frames, felt, and vulcanize rubber cushions were at an equilibrium state.

3.1.3 Laboratory Measurement Setup

The testing room was made to capture both surface flames and plume development. For the test the calorimetric extraction hood could not be used as the tested tables were too big to be positioned beneath.

To map the vertical thermal profile and convective column dynamics created by the combustion of the multi material tables (wool/synthetic felt, vulcanized rubber cushions, and dense hardwood frames), a spatial thermocouple grid was used and installed directly over the center of the table's playing surface.

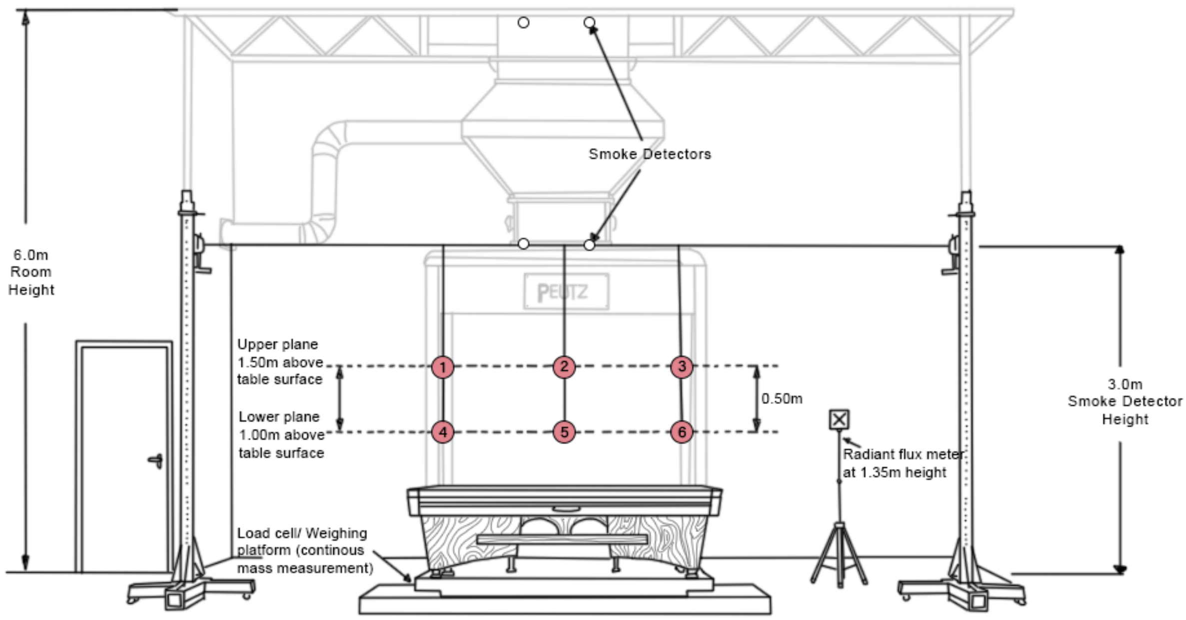

Figure 4: Schematics of the Experimental Testing Configuration at the Peutz Laboratory

The vertical thermocouple array was made in two distinct spatial planes to monitor the near-field and mid-field buoyant plume temperatures:

Upper measurement plane: Thermocouples 1,2, and 3 were placed horizontally and suspended at a fixed height of 1.5 m above the upper surface of the table .

Lower measurement plane: Thermocouples 4,5, and 6 were positioned in a parallel horizontal setup suspended at a fixed distance of 1.0 m above the table .

The setup recorded the conversion of localized area-source fire into a convective plume column, Monitoring the gas temperature profile as air entrainment occurred over the sides of the table. Real-time data logging for all thermocouple devices and load measurement devices was synchronized and logged continuously at a standard high frequency sampling interval of 1.00 seconds.

3.1.4 Data Acquisition and Calculations

For the specimens the continuous Mass Loss Rate (MLR) was evaluated using a linear derivative trend calculated over successive logging intervals:

$$[eq.2]\ \dot{m}_{loss} = \frac{m_t - m_{t-\Delta t}}{\Delta t}\ [kg/s]$$

To be able to use the results in the CFAST simulations the bridge between the physical experiments and the simulation model have to be leaped. CFAST needs a thermal output to create a deterministic model. The instantaneous Heat Release Rate (HRR) is calculated by coupling the mass loss metrics with the effective heat of combustion assigned to the composite fuel components:

$$[eq.3]\ \dot{Q} = \dot{m}_{loss} \cdot \Delta H_{c,eff}\ [kW]$$

Where:

$\dot{Q}$: represents the total estimated generated energy output (kW)

$\Delta H_{c,eff}$: is the effective heat of combustion derived from the material fractions (MJ/kg), incorporating the values of the hardwood frame (19 MJ/kg), vulcanized rubber (27 MJ/kg), and composite wool/nylon textile blends (23 MJ/kg)

3.2 Multi-Zone Modeling Framework (CFAST)

To translate the object specific fire curves retrieved during the full-scale laboratory testing (Section 5.2.1 and 5.2.2) into actual hazard profiles, a numerical modeling approach is needed. While Computational Fluid Dynamics (CFD) codes with the iterations the fluid flow, the Fire Dynamics Simulator (FDS) track several dimensional field variables at microscopic grid scale. Their execution demands differ a lot in the required computational power, which can restrict multiple scenario sensitivity analyses.

For greater volumes such as the central atrium of the senior housing complex, a lumped-parameter, two-zone deterministic fire model can be effective. This research uses the Consolidated Model of Fire and Smoke Transport (CFAST, version 7.7.5) developed by the National Institute of Standards and Technology (NIST) [31]

The CFAST simulations are based on solving a system of ordinary differential equations a based on the conservation of mass and energy within two different, vertically stratified fluid layers: The upper zone containing accumulated thermal combustion gases, and the lower zone containing uncontaminated ambient air. This way a computationally efficient analysis can be conducted for the Available Safe Egress Time (ASET), also allowing for several simulations where the geometric conditions differ.

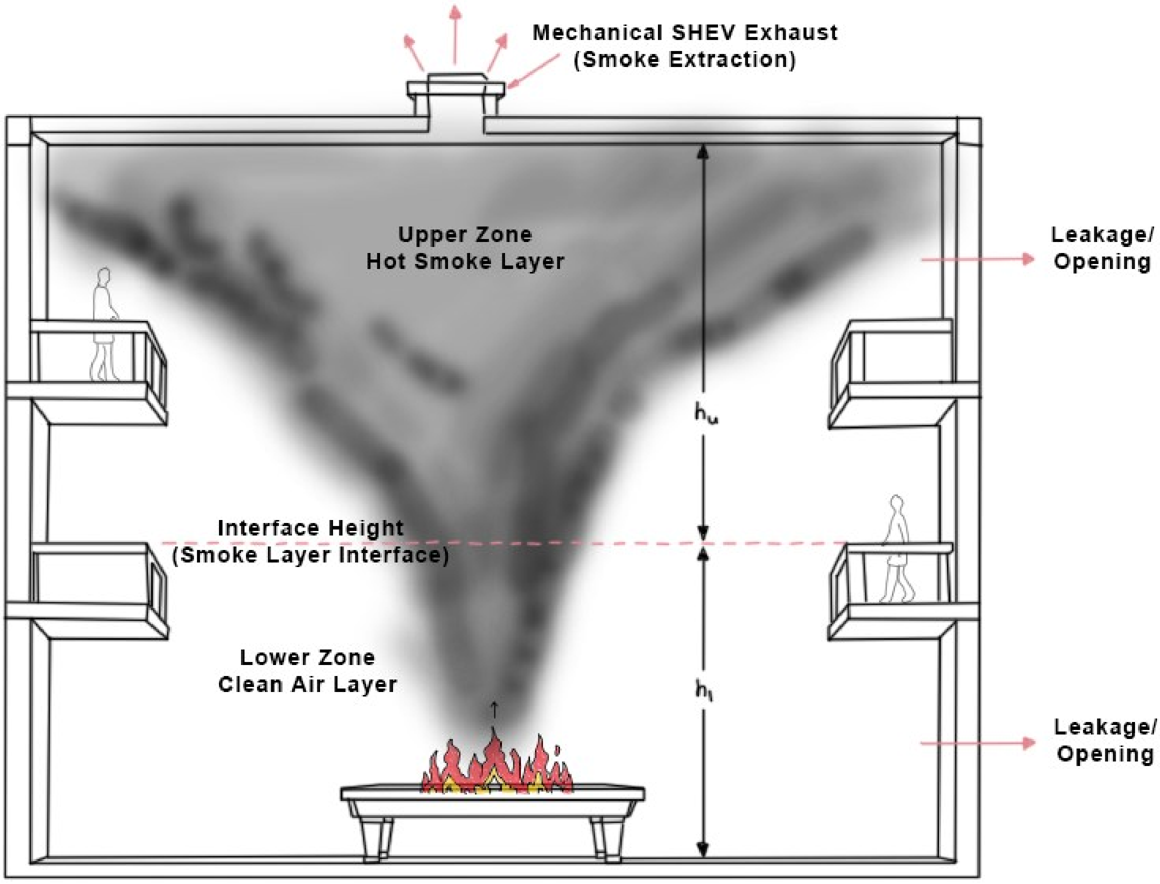

Figure 5: CFAST Two-Zone Smoke Model

3.2.1 Geometrical Simplification and Compartmentation

The layout of the central atrium in elderly housing (See Appendix B for Floorplans and Sections) has an open communal environment which is surrounded by residential apartments on multiple floor levels. To perform a multi-zone simulation, this spatial arrangement has to be simplified into defined rectangular based control volumes. This simplification reduces unnecessary geometric details while keeping the basis of the fluid-dynamic volume relationships that lead smoke layer descent.

The baseline case study geometry is created based on the dimensions retrieved from the floorplan documents received from the VRZHZ.

The total floor area: setup with a baseline depth of 10.15 meters and a width of 22.15 meters.

Clear elevation height: Input as a parameter that is 10.79 meters.

The physical connections to adjacent spaces, such as apartment corridors and staircases, are modeled using defined flow boundaries. This reassures that the calculated pressure gradients drive realistic mass and heat transfer across the compartment volume

For the parametric analysis the following parameters were used:

The total floor area: Varying parameter between 56.0 m^2 and 900.0 m^2

Clear elevation height: Variable parameter between 2.75 meters and 44.0 meters

3.2.2. Boundary Materials

The upper smoke layer cooling and the transition to thermal equilibrium are driven by conductive heat losses through the boundaries. CFAST needs explicit inputs for the thickness and thermal properties of all boundary layers to solve the one dimensional Fourier conduction equation across the internal wall, floor and ceiling profiles:

The structural elements of the elderly housing atrium are divided into three main material categories, with their own thermophysical properties described in Table 3.

Table 3: Properties of Separation Construction Elements

Separation Element	Material	Thickness [mm]	Thermal Conductivity [W/mK]	Density [kg/m3]	Specific Heat [J/kgK]	Emissivity [-]
Floor	Structural Concrete	200	1.20	2 300	880	0.94
Ceiling/Roof	Reinforced Concrete	150	1.20	2 300	880	0.94
Walls	Sand-lime Brick	150	0.70	1 600	840	0.90

3.2.3 Smoke Infiltration, Mechanical RWA Ventilation, and Vents

The movement of smoke and the place of the layer interface depend on the balance between the expansion of the gases by the fire and the mass flow rates through natural openings. Leakage paths are present because of construction inaccuracies and window frames. These are taken into account by inserting equivalent leakage areas at the floor and ceiling levels.

Table 4: Vent Placements Across the Simulation Model

Vent Placement	Boundary Location	Area [m2]	Height [m]	Profile/ Capacity
Main Entrance Doors	Atrium to Outside	4.20	0.00-2.10	Fixed open, to simulate exit scenario
Upper Circulation Vents	Atrium to Galleries	2.50	3.50-4.50	Closed baseline, track leakage route
Mechanical SHEV Exhaust	Roof Plenum	N/A	7.20/12.00	Extraction Possibility (Not Active)
Natural Air Supply	Ground Level	6.40	0.00-1.00	-

The mechanical Smoke and Heat Extraction System (RWA) is modeled based on the specifications of the actual senior housing installations, however this system is out of operation [35].

As mentioned in the building physics consultancy's report, recent renovations deactivated the automated thermal activation link for this system [35] As a result, the activation time is modeled using two different methods: a manual intervention delay and a complete failure scenario. These scenarios make sure that the cases are simulated for the worst case scenarios.

3.2.4 Translation of Experimental Heat Release Rates (HRR)

The fire source in CFAST can be defined by the datasets gathered from the laboratory experiments at the Peutz laboratory (Section 4.1). Rather than using idealized curves, the fire source uses real time series input of the Heat Release Rate and Mass Loss Rate.

To be able to see the real risk of the carambole billiard table, the combustion chemistry have to take into account the several materials included in the table.

The gas production rates for toxic species were not recorded during the experiments, therefore conservative values will be used for these parameters:

> *Soot Yield Factor:* a conservative value is set to reflect dense smoke produced by the table
>
> *Carbon Monoxide Yield:* fixed in the beginning, increases if the local oxygen concentration drops
>
> *Hydrogen Cyanide Yield:* accounting for the polyurethane padding and wool fibers within the table assembly

Note: Data from the Carbon Monoxide meters of the experiment conductors were received, however as they moved across the space during the experiment this data cannot be reliably used. (see Appendix K)

3.2.5 Parametric Analysis Matrix

To transform the case of the senior housing complex into a general framework that is sufficient for use by regional safety authorities like the Veiligheidsregio Zuid-Holland Zuid (VRZHZ), a parametric analysis matrix was developed. This way the building geometries and ventilation reliability are varied across 49 distinct simulations, avoiding conclusions based on a single layout.

The geometric variants change the base ratio of the atrium floor. The simulations show how different volumes affect smoke storage capacity and cooling rates.

Table 5: Parametric Analysis Matrix Simulation Numbering and Scenarios

Floor Area (A_f) [m^2]	H = 2.75 m	H = 5.5 m	H = 7.3 m	H = 11 m	H = 16.5 m	H = 22 m	H = 44 m
56.25	1	2	3	4	5	6	7
112.5	8	9	10	11	12	13	14
150	15	16	17	18	19	20	21
225	22	23	24	25	26	27	28
337.5	29	30	31	32	33	34	35

450	36	37	38	39	40	41	42
900	43	44	45	46	47	48	49

This simulation matrix evaluates geometric boundaries by pairing different floor areas with different atrium heights. The resulting data gives the technical base for determining certain conditions under which a billiard table can be safely kept in it's place in a common room or escape route.

3.3 Evacuation Modeling Framework with Pathfinder (RSET)

To determine the Required Safe Egress Time (RSET), this research uses Pathfinder (version 2026.1), an agent based evacuation simulator developed by Thunderhead Engineering [21]. Pathfinder simulates the movement of individuals using a geometric mesh. This way also the spatial shortcomings are taken into account, such as corridor interactions, and specific occupant behaviors. As a result a more detailed analysis can be conducted than traditional movement calculations.

3.3.1 Pathfinder Setup

The Pathfinder model is built using the floorplans of the senior care facility. The simulation space recreates the ground floor atrium, the first floor and the second floor residential galleries that overlook the main space.

The residents number of the building is set to a baseline of 40, from which 20 are located within the atrium zone and immediate corridor spaces. The other 20 is located in their living units. The total population of 40 people is categorized into different profiles based on physical mobility to realistically represent the demographics of an elderly care facility:

Total Population (Including care workers): 42

Table 6: Distribution and Walking Speeds of the Population of Senior Housing

Percentage of Population	Type of Resident	Number of Residents	Walking Speed of Resident Type
36%	Unassisted Seniors	15	Max Velocity:1.0 m/s
12%	Rollator-reliant	5	Max Velocity: 0.5 m/s
48%	Staff-Dependent	20	Controlled by Care Personnel (Maximum 2)
4%	Care Worker	2	-

The spatial layout assumes that the primary exit path leads through the main atrium doors. Secondary emergency exits are initially locked or can be unfamiliar (evacuation to another building such as Gebouw A or C), forcing the residents to prioritize paths that pass near the location of the fire source.

3.3.2 Kinematic Settings and Walking Speed

Pathfinder calculates the movement of people using a steering mode, that is based on Reynold's behavioral algorithms [32]. This method repeatedly adjusts the individual velocity vectors to avoid collisions with wall, obstacles and other people.

To allow a more precise modeling of the elderly care scenario, the kinematic settings are not set to standard able bodied adult values. Instead, they use the reduction frameworks defined in Section 3.2.4 of the Swedish Building Code (BBRAD) [3].

Table 7: Pre-Movement Time Depending on Occupant Group

Occupant Group	Walking Speed [m/s]	Shoulder Width [cm]	Pre-Movement Response Delay [s]	Navigation Logic
Independent Seniors	1.0 m/s	45.0	240 s	Preference for main exits
Rollator-Reliant	0.5 m/s	65.0	240 s	Wide paths are needed, tries to avoid stairs
Staff-Dependent*	0.2 m/s	50.0	Waits for care worker to be moved	Stays stationary until assisted
Care Worker	1.5 m/s	45.9	60 s	Assisting residents that need support

**Note on Staff-Dependent residents: Pathfinder does not take into account that the staff-dependent residents have to be assisted out of the bed and transported in a wheelchair. (By default the staff member arrives to the patient and they proceed right away without stopping) This is not realistic, therefore this difference was taken into account in the walking speed of the staff-dependent people and further reduced to make the evacuation time more accurate.*

The simulation takes into account the delay which is associated with the human mental processing of an emergency, physical preparation, and staff notification in a care facility.

For independent residents, the parameters average a detection and response delay time of 60 seconds. For rollator-reliant inhabitants, the parameters increase the average delay to 240 seconds.

The staff dependent users remain stationary until a Care Worker/ Personnel reaches their location, simulating the time that is needed for staff to assist residents during a night or day shift with low staffing levels (two active nurses). [35]

3.4.3 Pathfinder Scenario Analysis Matrix

Table 8: Pathfinder (RSET) Scenario Analysis Matrix

Version Name	Description	Number of people	Day/night	Door behaviour
Simulaiton_1	Evacuation with normal able bodied people	299	n/a	n/a
Simulaiton_2	Evacuation with actual number of people with 1 evacuating personeel, everyone in building	69 (47)	night	closest exit
Simulaiton_2.2	Evacuation with actual number of people with 2 evacuating personeel, everyone in building	47	night	closest exit
Simulaiton_2.3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, less known exits are not used	45	night	less known exits not used
Simulaiton_2.4	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, less known exits are not used	46	night	less known exits not used
Simulaiton_2.5	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, only main exits are used on ground floor	45	night	only main exits are used on ground floor
Simulaiton_2.6	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, only main exits are used on ground floor	46	night	only main exits are used on ground floor
Simulaiton_3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building	69	day	closest exit
Simulaiton_3.2	Evacuation with actual number of people with 2 evacuating personeel, everyone in building	70	day	closest exit
Simulaiton_3.3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, less known exits are not used	69	day	less known exits not used
Simulaiton_3.4	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, less known exits are not used	70	day	less known exits not used
Simulaiton_3.5	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, only main exits are used on ground floor	69	day	only main exits are used on ground floor

Simulaiton_3.6	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, only main exits are used on ground floor	70	day	only main exits are used on ground floor
Simulaiton_4	People who are in their room stay there, only atrium people are evacuated, 1 evacuator	49	day	all exits possible
Simulaiton_4.2	People who are in their room stay there, only atrium people are evacuated, 2 evacuator	50	day	all exits possible

3.4 Tenability Criteria for ASET (Available Safe Egress Time)

To determine the exact second the Available Safe Egress Time (ASET) is not met, the CFAST output values are analyzed and processed using computational expressions from ISO 13571 [9] and the performance based framework [22][13]. The tenability limit is compromised the moment any of the three following environmental limits are exceeded at a height of 1.60 meters above the uppermost level of the atrium or the upper galleries.

3.4.1 Optical Density

Smoke disturbance is evaluated by the optical density extracted from the CFAST simulations. In order to get the visibility distance, 1.3 (represents black smoke in cellulose fires) have to be divided by the optical density as follows:

$$S = \frac{1.3}{Optical\ Density}\ [m]$$

Tenability Limit: The ASET endpoint is strictly triggered if V<10.0 meters inside the large open volume of the atrium. If the visibility of a space is V>100.00 meters throughout the whole fire scenario, full evacuation is not necessary and the stay-in-place concept can be considered.

3.4.2 Fractional Effective Dose for Toxic Gases (FEDtoxic)

The cumulative risk to vulnerable, low-mobility occupants is calculated using the Fractional Effective Dose (FED) defined in ISO 13571. This equation takes into account addition of carbon monoxide (CO) and hydrogen cyanide (HCN) exposures over time:

$$[eq.4]\ FED_{toxic} = \int_0^t \left(\frac{[CO]}{35000} + \frac{[HCN]^{1.4}}{1.2 \times 10^6} \right) \cdot \Delta t$$

Where [CO] and [HCN] are the time-resolved concentrations (ppm) calculated within the lower breathing zone or descending smoke layer interface.

Tenability Limit: While the standard fire design permits an FED ≤ 1.0 for healthy populations, this research uses a strict safety threshold of FED_{toxic} ≤ 0.30 to protect elderly people who have preexisting cardiovascular and respiratory vulnerabilities. [9] [13]

3.4.3 Thermal Radiation and Convective Heat Exposure ($FED_{thermal}$)

The localized radiant heat flux ($\dot{q}_{rad}$) emitted by the descending smoke layer and the active billiard table flame is tracked alongside the convective air temperature (T_{gas}). The time to skin pain or second degree burns from convective heat exposure is calculated using the fractional thermal dose model:

$$[eq. 5]\ FED_{thermal} = \int_0^t \frac{1}{t_{cr}} dt = \int_0^t \frac{1}{5.0 \cdot 10^7 \cdot T_{gas}^{-3.61}} dt$$

Tenability Limit: The thermal threshold is compromised if the radiant heat flux at head height exceeds $\dot{q}_{rad} = 1.0\ kW/m^2$, or if the cumulative convective dose reaches $FED_{thermal} \geq 0.30$ (corresponding to short-term exposure to air temperatures exceeding 80°C. [23][9]

3.5 Stay-in-Place Concept

The quantitative data collected from the CFAST and Pathfinder simulations allows for an evaluation of the evacuation strategy from a performance based point of view. Traditional prescriptive fire safety frameworks assume rapid fire development which makes immediate and total evacuation of the fire compartment necessary. However, the simulation results give a technical basis for considering other strategies, such as the Stay-in-Place concept.

To evaluate this option, a two-threshold criteria system will be used based on the exposure duration of the occupants:

Short Term Evacuation Criterion: A visibility threshold of 10 meters is needed for active evacuation scenarios where occupants are exposed to smoke for a limited duration (around 5 minutes).

Partial Evacuation Criterion: A visibility threshold of 30 meters is needed for the atrium to be evacuated. This ensures safe conditions in individual compartments, but urges to evacuate the fire compartment itself.

Unlimited Exposure Criterion: A visibility threshold of 100 meters is used if occupants remain within the space without a time limit, as this great level of clear air ensures the carbon monoxide (CO) and soot accumulation are negligible from a toxicity point of view.

4 Experimental Results and Analysis

This chapter presents the findings from the fire laboratory experiments conducted at the Peutz facility in Haps. The main goal of these experiments was to determine the real world fire behavior, mass loss rate (MLR), and corresponding Heat Release Rate (HRR) of a standard billiard table under controlled ignition conditions. These insights give a base for the multi-scenario simulations executed in CFAST.

4.1 Experimental Setup, Boundary Conditions

The laboratory tests were designed to evaluate three billiard tables in the same configuration, focusing on their ignition point, pyrolysis and transformation from localized smoldering to full scale flaming combustion. The two/three experiments were defined as a minimum requirement to ensure that the data retrieved from the experiments is reliable.

Due to asbestos contamination of one of the billiard tables, it had to be excluded from the experiment. Therefore, the experimental phase continued with two billiard tables.

Figure 6: Wooden Cribs and Starting Block used for Starting the Fires

4.1.1 Ambient conditions

The experiments were conducted outside of the exhaust hood as the size of the specimens did not allow for being placed under the hood. The base conditions in the laboratory were stable throughout both tests:

Ambient temperature: 18.55°C

Relative Humidity: 48% (estimation)

4.1.2 Toxicological Limitations

The main instrumentation consisted of electronic load cells below the test platforms to monitor the mass loss, along with several thermocouples positioned at varying heights and distances form the fuel core to chart the thermal profile of the fire plume.

It is important to emphasize the boundary condition regarding the gas analysis: toxicological sampling for CO and HCN was not used in the experimental phase. Handheld CO life safety monitors were carried by the test conductors for occupational safety purposes. While these devices recorded localized, transient spikes in Carbon Monoxide (with a peak recorded at 26ppm as detailed in the event logs), this data is unreliable due to the continuous positional changes of the operator. As a result, this data cannot be treated as a scientifically accurate, spatially fixed metric for gas yield calculations. The data about the CO meters can be found in Appendix K as an observational addition. The actual toxic source terms (CO) and soot yields are instead added through conservative literature values within the simulation framework.[2] (See Appendix G)

4.2 Mass Loss Rate (MLR) Analysis

The mass loss rate serves as the final indicator of fuel consumption and pyrolysis speed. Data from the load cells was logged at 1 second intervals. Due to the sensitivity of the electronic scale, even small structural changes on the timber frame triggered a change. Therefore the raw data showed a lot of measurement noise.

To separate the macro pyrolysis trend from this mechanical noise, a moving average filter was applied across a rolling window of 60 seconds. This data smoothing process ensures that the following mass calculations reflect actual material gasification rather than the small scale vibrations.

4.2.1 Table Configuration 1 (Test 1)

Test 1 used a traditional hardwood/MDF composite sub-frame setup.(see Appendix D) According to the ignition method and external energy source (a standardized wood crib and a starting block) were used to start the fire during the experiment.

Initial Weight: 1054.70 kg

Post-Test Final Weight: 1053.7 kg

Gross Consumption: 1.09 kg over an active observation window of 891 seconds.

The mass tracking data shows that despite the repeated application of the ignition source, the materials in the table failed to reach a self-sustaining fire condition. The mass loss was localized, limited to the close environment of the heat application. The charring of the timber frame happened at an incredibly slow pace. This behavior is mostly lead by the high thermal inertia of the hardwood timber components and the massive stone slate right above the core layout of the table structure. The slate plays a vital two way role: firstly it is a massive heat sink, constantly conducting thermal energy away from the frame components, therefore lowering the surface temperature below the critical ignition threshold of 300°C, what is needed for quick pyrolysis.

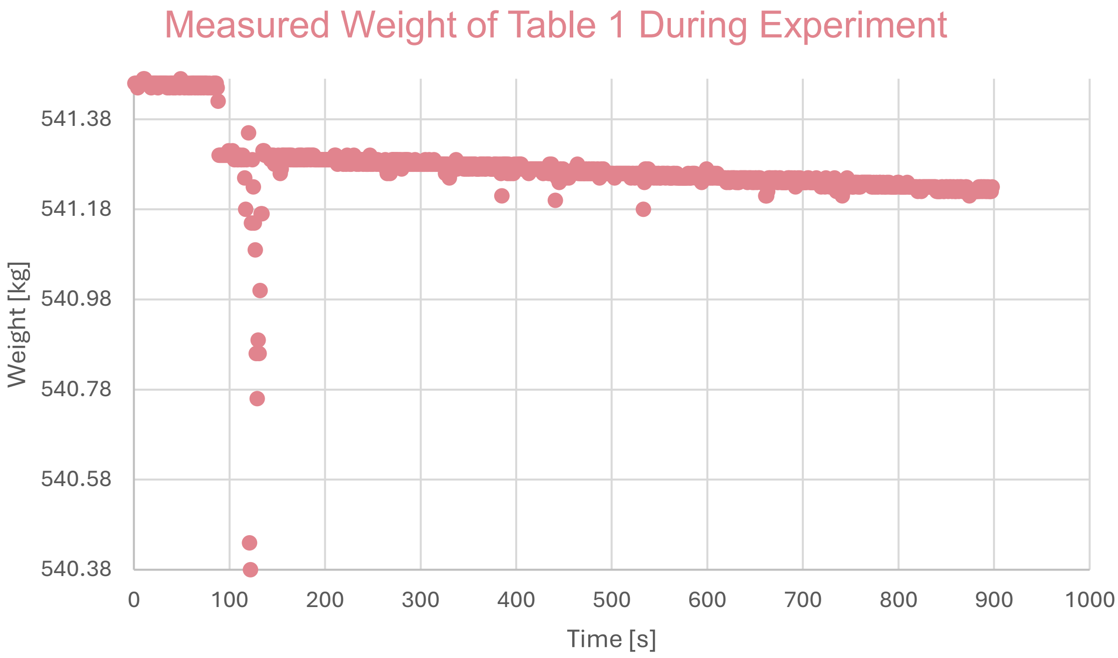

Figure 7: Measured Weight of Table 1 During Experiment

4.2.2 Table Configuration 2 (Test 2)

Test 2 evaluated a somewhat different type of billiard table, having a more simple wooden geometry, with less overall weight. (see Appendix E)

Initial Weight: 669.41 kg

Post-Test Final Weight: 668.6 kg

Gross Consumption: 0.81 kg over an active observation window of 891 seconds.

The similar mass loss rate of 1.09kg and 0.81kg between the different configurations emphasizes an important principle: the combustion of a billiard table is independent of minor geometric changes under similar ignition scenarios. The process is fuel controlled and suppressed by the composite construction.

Several tests were carried out to see whether the table could be brought into a full flaming condition. The wool-nylon felt covering the playing surface carbonized upon contact with heat, forming a protective char layer that insulated the frame below, from an accelerated fire spread. The timber frame showed some charring and smoldering but failed to show any signs of transition to a flaming fire.

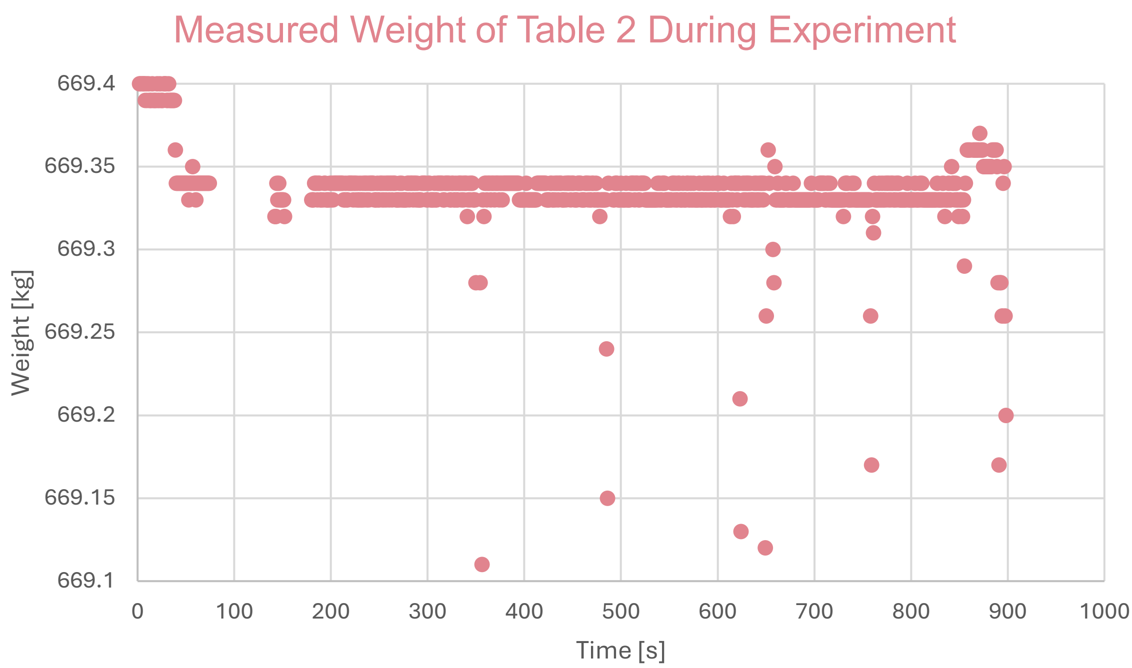

Figure 8: Measured Weight of Table 2 During Experiment

4.3 Heat Release Rate (HRR) Derivation

Normally, the experimental HRR of a fuel package that burned in an open or semi-enclosed environment is calculated via the mass loss using Equation 3 (Section 4.1.4)

$$[eq.3]\ \dot{Q} = \dot{m}_{loss}\Delta H_{c,eff}[kW]$$

For the main combustible sub-frame (hardwood and fiberboard), the effective heat of combustion ΔH_c was based on the baseline from Eurocode 5 (EN1995-1-2) and was 19 000 kJ/kg. This property is just as of timber, which undergoes thermal degradation.

4.3.2 Analysis of HRR Curves

The derived HRR curves for both experiments confirm that the billiard table is only a low-intensity smoldering heat source, rather than an energy-producing fuel hazard.

Peak HRR (Test 1 & Test 2): The maximum calculated energy output peak consistently below the 4.0kW threshold during the weight shifts, with a very small average domain of 0.05 kW to 0.20 kW

Fire Growth Profile: There are no characteristic exponential t^2 fire growth curves observed. Instead, the HRR profile is assumed flat, with a plateau, which represents a steady smoldering and local charring.

To put these numbers into context, a wastepaper basket fire usually generates a peak HRR between 50kW and 100kW, while the burn of a modern chair quickly climbs past 250kW to 500kW. The maximum output of the billiard table is <4kW, means that the convective thermal plume is negligible. The energy content of the ignition source itself exceeded the convective contribution of the table framework, providing that the table is an inert mass that limits fire development rather than promotes flame spread.

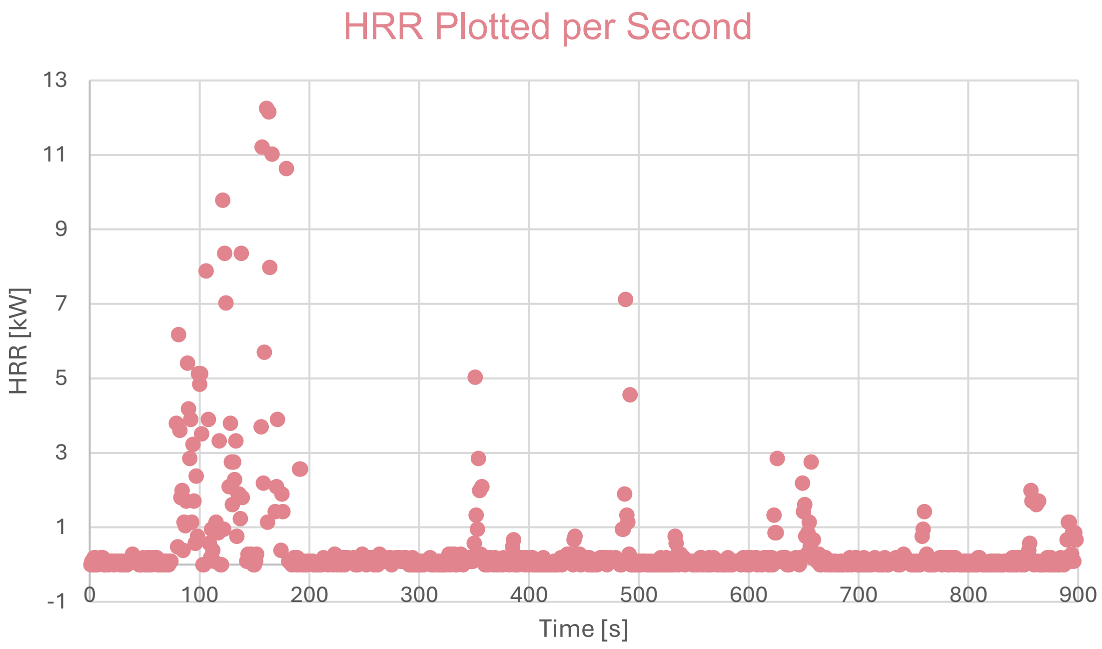

Figure 9: HRR Plotted per Second

Figure 10: HRR with Moving Average of 60 seconds

4.4 Thermal Profile and Ambient Temperature Variations

The thermal affect of the fire on the surrounding environment was tracked using six thermocouples from TK1 to TK6. The resulting temperature logs show that the smoldering fire was unable to change the temperature of the laboratory space.

Baseline Air Temperature: 18.55°C

Maximum Recorded Local Temperature: 18.66°C

This shows a maximum localized temperature rise ΔT of just 0.37°C to 0.65°C , restricted to the air layer inside the thermal plume. Thermocouples registered no significant deviation from the baseline laboratory temperature.

4.4.1 Significance of the Thermal Logs

From a fire dynamics perspective, this lack of temperature increase results in three main insights:

Absence of Flashover Potential: The billiard table cannot generate enough energy to form a hot smoke layer, which is capable of radiating. This closes out the risk of transition to flashover within the escape route.

Negligible Buoyant Driving Force: Plume buoyancy is directly proportional to the temperature difference between the plume gases and the surrounding air ΔT. Because ΔT is less than 3.5°C the smoke lacks the buoyancy needed to go through quickly, a pressurized lateral spread along a corridor ceiling.

No Structural Thermal Threat: The convective and radiant heat flux directed toward building occupants being evacuated or surrounding structural elements is basically zero, falling well below the strict tenability limit of 1.0kW/m^2 specified in the Appendix J.

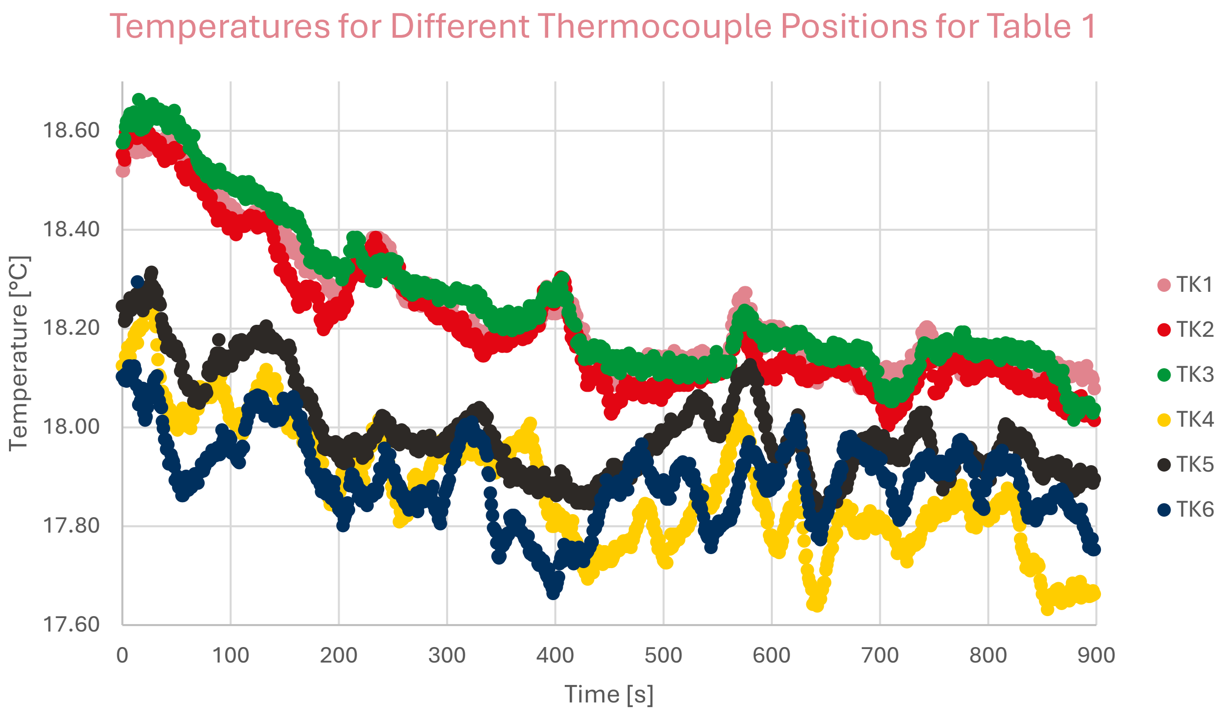

Figure 11:Temperatures for the Different Thermocouple Positions Measured During the Experiment for Table 1

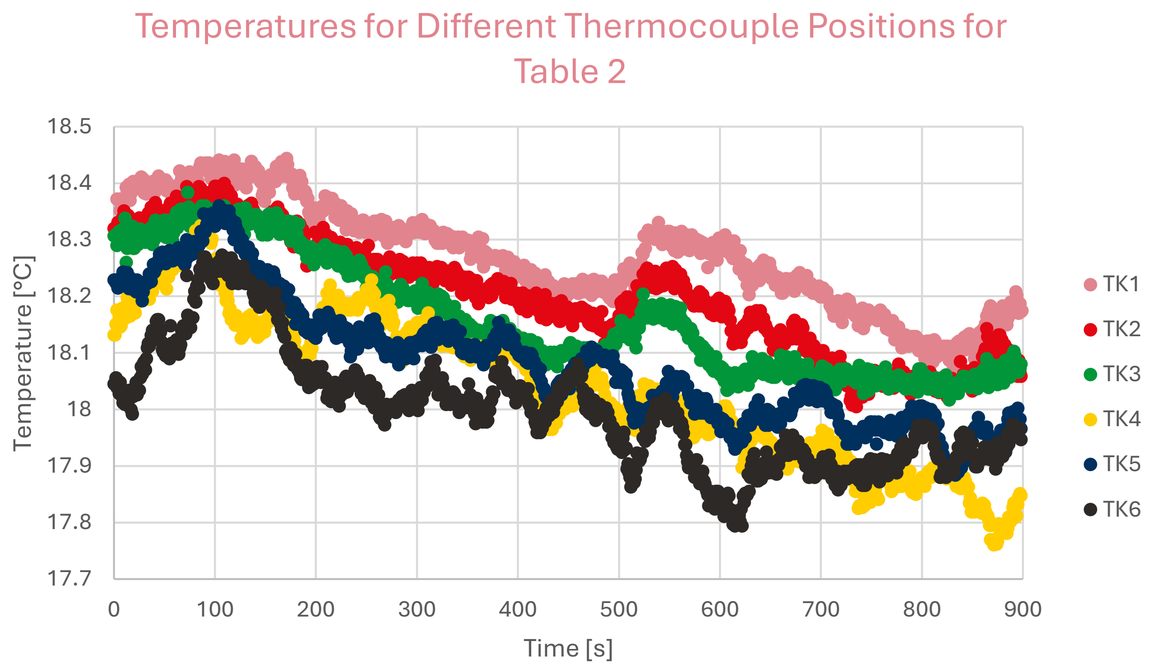

Figure 12: Temperatures for the Different Thermocouple Positions Measured During the Experiment for Table 2

4.5 Observations and Smoke Production

While the thermal danger of the billiard table is low, its smoke production needs analysis, as smoke transport impacts visibility and tenability criteria in senior residential escape routes.

4.5.1 Observations and Time to First Smoke

The visual timeline across both test followed a similar pattern:

t=0 s: Starting the ignition source in the table

t=12s to t=15s: First observable gassing and wispy smoke production. This smoke generation is caused by the pyrolysis of the starting block and wooden crib.

t=60s: The smoke production is continuous, low-velocity gray plume is seeable. The smoke was driven by the thermal updraft of the ignition source rather than a sustaining flaming from the table itself.

t=120s to t=891s: The system settled into a steady smoldering phase. The timber frame charred slowly, producing a low-volume smoke output. The flame front did not spread across the table geometry, therefore it remained completely localized around the ignition place.

4.5.2 Smoke Characteristics

The smoke produced in the smoldering phase was characterized by a light gray color, meaning incomplete combustion that is oxygen controlled and dominated by low temperature pyrolysis of products. Because the rubber cushions and synthetic components were not exposed to a high-temperature flaming, the dense, black soot that usually appears in developed synthetic fires were not observed.

However, because smoldering fires have a high soot-yield coefficient due to incomplete combustion, this steady generation must be treated with caution. Even though the volumetric production rate is low due to the low mass loss rate, the high soot yield means that the smoke's light compromising properties must be evaluated.

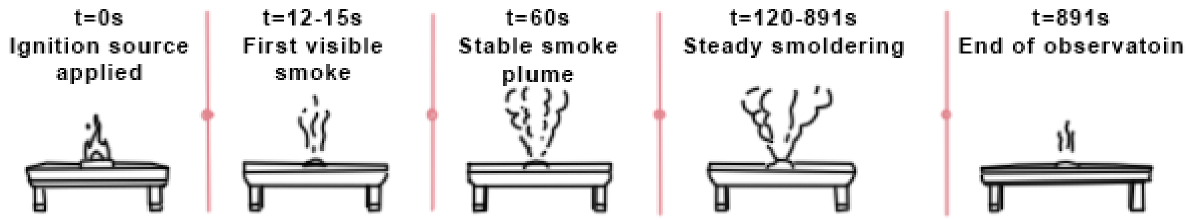

Figure 13: Smoke Production Timeline – Visual Observation

5 Simulation Results and Analysis

This part presents the numerical results of the simulation study. The analysis is divided into two main sections: the fire and smoke simulations computed with CFAST, and the evacuation timelines generated with Pathfinder. The simulations models are developed in such a way that they reflect the low-intensity smoldering characteristics, which were observed during the laboratory testing.

5.1 CFAST Baseline Fire and Smoke Spread

The baseline simulation shows the central atrium of the senior housing (Bouwdeel B) under the material conditions identified during the experimental phase. As a result of the experimental findings, the fire is defined as a low-intensity, non-flaming smoldering fire rather than an idealized fast-growing fire.

To achieve a fully mixed, uniform distribution across the open volume, all connected compartment zones within CFAST are configured as shaft type volumes. The fire properties have been adjusted to model the low-energy pyrolysis of the medium-density fiberboard (MDF) sub-frame:

Effective Heat of Combustion (ΔH_c): Set at a constant 19 000 kJ/kg

Radiative Fraction (χ_{rad}): Adjusted to 0.0. This modification ensures that all energy released by the smoldering is transferred only via convective mechanisms. This reflects the lack of an open flame or a high-temperature radiant heat core.

Gas Species Yield Parameters: To match the partial combustion characteristic of smoldering timber, the baseline soot yield (y_s) has been doubled relative to default furniture values, and the carbon monoxide mass yield (y_{CO}) has been increased by a factor of 10.

5.1.1 Thermal and Layer Height Development

The thermal output of the smoldering carambole billiard table is characterized by low energy output and minimal temperature development. Over the 1 800 second simulation time, the maximum computed gas temperature has an absolute peak of 20.13°C under standard operating conditions, matching the 18.0°C to 18.66°C absolute boundaries measured by the laboratory thermocouples. (see Figure 11 and Figure 12)

This small temperature difference relative to the 20.0°C ambient design temperature creates a very low buoyant plume force. The convective velocity is insufficient to cause rapid, pressurized smoke logging of the upper ceiling layer.

Instead, the thermal energy is transferred almost completely with slow convective diffusion. This behavior results in a delayed and uniform filling of the space rather than the sharp thermal stratification, which is more typical for fast-growing flaming fires.

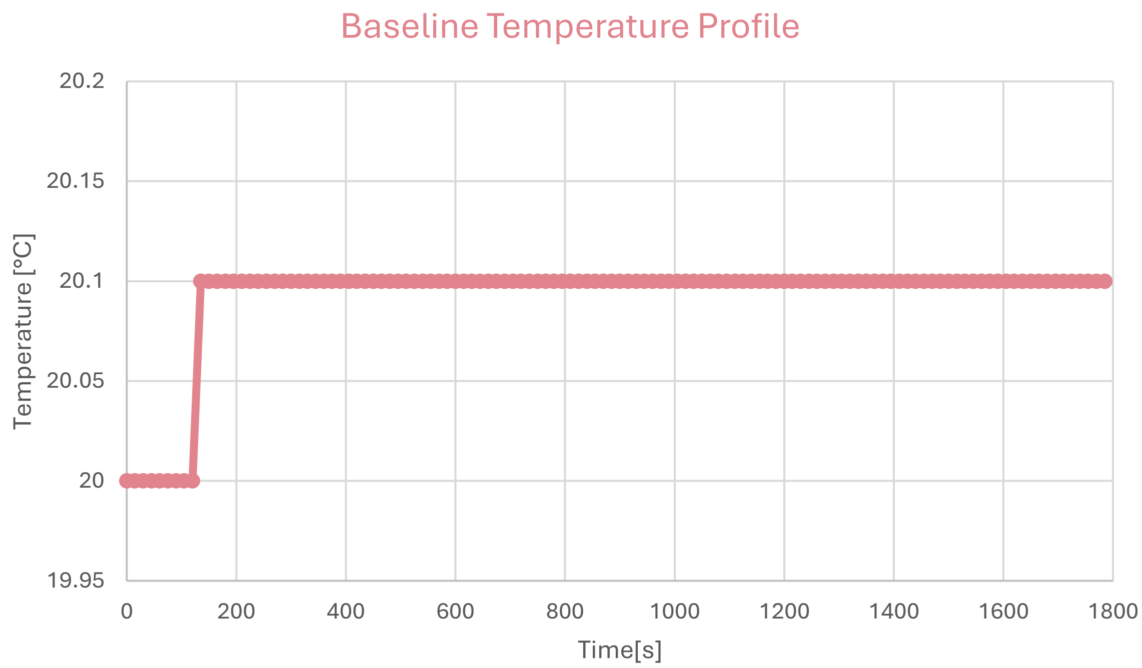

Figure 14: Baseline Temperature Profile

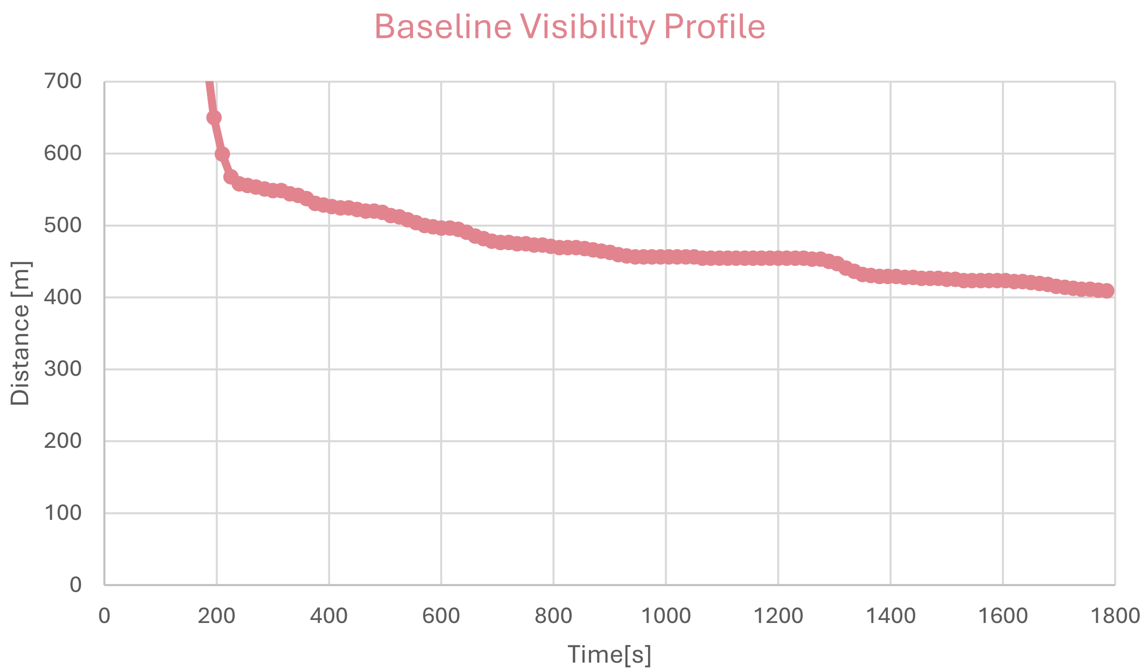

Figure 15: Baseline Visibility Profile (Showing Visibility Below 700m)

See Appendix I for full Baseline Visibility Profile Graph in the range of 0m to 18 000m.

5.1.2 Visibility and Hazardous Substance Accumulation

The main hazard that is generated by the smoldering furniture load is the constant reduction of path visibility, what is due to the low-temperature soot production. Because the radiative fraction is set to zero and the combustion is very under ventilated, the smoke particles do not have the thermal buoyancy to form a concentrated layer at the ceiling. Instead, they distribute evenly throughout the volume.

The baseline visibility trends are evaluated under two scenarios: in the first scenario with a mechanical smoke and heat exhaust ventilation (SHEV) system, and in the second scenario without the SHEV system.

Table 9: Results of the Baseline Scenario with SHEV and without SHEV

Parameter	Baseline With Mechanical SHEV	Baseline Without Mechanical SHEV	Safety Threshold
Peak Gas Temperature (T_{max})	20.13°C	20.13°C	≥80.0°C (Convective)
Total Visibility	409.22m	409.22m	<10.0 m – full evacuation <30.0 m – atrium evacuation

5.2 CFAST Parametric Geometric Analysis

To generalize these results beyond the layout of the elderly home, a parametric analysis study was conducted. This analysis varies the physical compartment dimensions to ensure that the findings support a broader safety framework for regional safety regions.

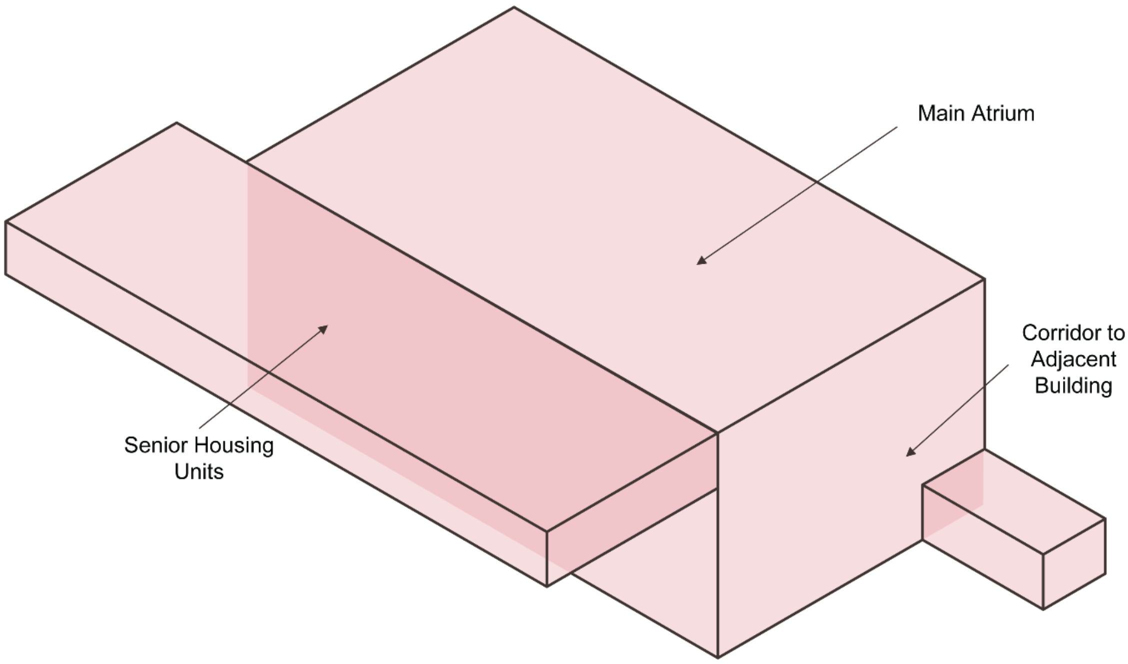

Figure 16: Schematic 3D Model of Geometry Used for CFAST Parametric Analysis

5.2.1 Thermal Parametric Grid

Table 10 shows the maximum gas temperatures across the full parametric grid, which includes floor areas from 56.25m^2 to 900.0m^2 against heights from 2.75m up to 44.0m.

Table 10: Parametric Analysis Temperature Results

Floor Area (Af) [m2]	H=2.75m	H=5.50m	H=7.33m	H=11.0m	H=16.50m	H=22.0 m	H=44.0m
56.25	21.10	20.72	20.58	20.41	20.29	20.23	20.12
112.50	20.50	20.36	20.29	20.22	20.16	20.12	20.06
150.00	20.34	20.27	20.22	20.16	20.12	20.09	20.05
225.00	20.19	20.17	20.14	20.11	20.08	20.06	20.03
337.50	20.11	20.10	20.08	20.07	20.05	20.04	20.02
450.00	20.07	20.07	20.06	20.05	20.04	20.03	20.02
900.00	20.07	20.03	20.03	20.02	20.02	20.01	20.01

The data shows that thermal tenability is kept at a sufficient level across all evaluated geometric setups. Even in the smallest and lowest compartment setup (A_f=56.25m^2, H=2.75m), where convective energy is spread over a volume of 154.69m^3, the peak temperature reaches just 21.10°C. This shows that the temperature rise is only 1.10°C above base conditions, which poses zero thermal risk. Therefore, there is no need to evacuate the residents either.

As the volume increases upward to a large atrium configuration (A_f=900m^2, H=44.0m), the thermal energy from the smoldering source dissipates into the volume, resulting in minimal temperature change to 20.01°C.

5.2.2 Visibility Parametric Analysis

While the temperature changes remain negligible, the visibility varies significantly with the different building geometries. Table 11 shows the visibility in the volumes in meters. The number means how far a healthy individual would be able to see with the existing smoke density conditions in an unobstructed field.

Table 11: Parametric Analysis Total Visibility Results

Floor Area (Af) [m2]	H = 2.75 m	H = 5.5 m	H = 7.3 m	H = 11 m	H = 16.5 m	H = 22 m	H = 44 m
56.25	29.3	59.8	79.77	120.85	181.92	243.04	487.59
112.5	58.06	118.42	157.92	239.16	359.93	480.7	963.9
150	77.17	157.39	209.86	317.77	478.17	638.55	1280.23
225	115.37	235.26	313.71	474.91	714.62	954.19	1912.78
337.5	172.76	352.28	469.75	711.6	1079.62	1429.65	2865.65
450	230.33	469.51	626.04	947.8	1426.01	1904.17	3816.44
900	453.13	922.74	1249.77	1862.78	2802.61	3742.33	7500.53

The data shows a linear relationship between the available clear height and the visibility across the small to medium compartment ranges. In certain cases (Af=56.25m^2, H=2.75m) visibility limits are compromised at 29.30m due to the smoke accumulation within the small overhead space.

On the other hand, enlarging the setup parameters increases the smoke storage capacity of the volume. In the baseline atrium scenario (A_f=337.50m^2, H=7.33m), the simulation calculates the minimum visibility to be 469.75m, which is close to the calculations conducted for a senior housing case study, where this number is 409.22m.

When the floor area reaches 900m^2 or the ceiling height goes to 44.0m, the visibility becomes 7500.53m, basically infinite. This shows that the volumetric capacity of the space can store or distribute the smoke over 1800 seconds, keeping clear visibility at head height without the need for mechanical extraction.

5.3 Pathfinder Evacuation Results

Occupant evacuation was simulated across multiple scenarios to determine the Required Safe Egress Time (RSET). These simulations take into account the differences in walking speeds, staffing levels, and exit availabilities.

Table 12: Pathfinder Simulation Results

Version Name	Description	Number of people	Day/night	Door behaviour	Escape Time [min]
Simulaiton_1	Evacuation with normal able bodied people	299	n/a	n/a	1.52

Simulaiton_ 2	Evacuation with actual number of people with 1 evacuating personeel, everyone in building	69 (47)	night	closest exit	20.05 83
Simulaiton_ 2.2	Evacuation with actual number of people with 2 evacuating personeel, everyone in building	47	night	closest exit	10.91 33
Simulaiton_ 2.3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, less known exits are not used	45	night	less known exits not used	19.84 17
Simulaiton_ 2.4	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, less known exits are not used	46	night	less known exits not used	11.11 67
Simulaiton_ 2.5	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, only main exits are used on ground floor	45	night	only main exits are used on ground floor	48.03 33
Simulaiton_ 2.6	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, only main exits are used on ground floor	46	night	only main exits are used on ground floor	25.20 83
Simulaiton_ 3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building	69	day	closest exit	14.48 33
Simulaiton_ 3.2	Evacuation with actual number of people with 2 evacuating personeel, everyone in building	70	day	closest exit	8.183 33
Simulaiton_ 3.3	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, less known exits are not used	69	day	less known exits not used	17.47 17
Simulaiton_ 3.4	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, less known exits are not used	70	day	less known exits not used	9.963 33
Simulaiton_ 3.5	Evacuation with actual number of people with 1 evacuating personeel, everyone in building, only main exits are used on ground floor	69	day	only main exits are used on ground floor	32.20 5
Simulaiton_ 3.6	Evacuation with actual number of people with 2 evacuating personeel, everyone in building, only main exits are used on ground floor	70	day	only main exits are used on ground floor	16.22 17

Simulaiton_ 4	People who are in their room stay there, only atrium people are evacuated, 1 evacuator	49	day	all exits possible	3.875
Simulaiton_ 4.2	People who are in their room stay there, only atrium people are evacuated, 2 evacuator	50	day	all exits possible	2.155

5.3.1 Impact of Staffing Levels

The evacuation time depends on the staffing level within the building. The simulation log shows the data for night configurations (low staffing) and day configurations (full staffing).

The baseline simulation (Simulation 1), which assumes healthy adult population moving unassisted, results in a fast evacuation time of 91.2 seconds. This shows that the physical properties, such as the width of the corridors and doors are well sized for standard occupant loads, who do not have any physical limitations.

However, when the occupant parameters are changed to reflect the actual senior demographics of a senior housing complex, using a 2/3 walking speed reduction as specified in the Swedish Building Code (BBRAD) [3], the evacuation times increase significantly. In the case of the night shift, when one staff member is present (Simulation_2), the required evacuation time is 1203.5 seconds, 20.06 minutes. This long duration time is due to the fact that several residents require assistance, which means that a dependent resident must remain stationary until the only working staff member assists them one by one out of the building.

Doubling the active night staff to two members (Simulation_2.2) reduces the total evacuation time to 654.6 seconds, 10.91 minutes. This clearly shows that the evacuation efficiency of vulnerable people is mostly limited to the staff availability, rather than the corridor capacity.

5.3.2 Influence of Exit Restrictions

The simulation matrix also evaluates how route familiarity and exit accessibility affect the evacuation time. When residents are restricted from using secondary, less familiar emergency doors, forcing them to rely on the main exits (Simulaiton_2.4), the night shift evacuation time with two staff members goes up slightly to 667.2 seconds.

The most critical strategic shortcoming happens during the daytime scenarios when occupants are lead only through the main groundfloor atrium exit doors (Simulation_3.5 and Simulation_3.6). If only one staff member is available to assist the residents through this one main exit path, the evacuation time increases to 1932.6 seconds, 32.21 minutes. This great delay is because localized crowding can occur and taking residents out of their beds adds extra time that is needed for the evacuation.

5.4 ASET/RSET Comparison and Tenability Assessment

To create a strong equivalent safety justification, the Available Safe Egress Time (ASET) trends derived from the fire models must be compared with the Required Safe Egress Time (RSET) distributions calculated across the occupant scenarios.

The smoldering fire established during the laboratory testing, the building maintains a high safety margin across all layout variations. Because the soot generation is low and the temperature stays close to ambient levels (20.13°C), the available safe egress time exceeds the simulation timespan. This ensures that the safety margin always remains positive:

$$ASET_{smold} - RSET_n > 0$$

This condition is true even when the extended evacuation scenario is taken with 1932.6 seconds, in case of one staff member being available, and only the main exit being used.

However, when the volume of the spaces decreases, the visibility of the spaces decreases, but still this does not change the ASET value. During the day shift, when highly staffed (Simulation_3.2), the RSET value is 490.8 seconds. When compared with the visibility limit, this results in a safe condition.

$$\Delta t_{margin} = \infty - 490.8s = \infty$$

The result shows that even for greater RSET, the evacuation remains safe.

During the night shift with minimal staff (Simulation_2) the RSET is 1203.6 seconds, still resulting in safe conditions:

$$\Delta t_{margin} = \infty - 1203.6s = \infty$$

In this second example again, the safe evacuation is ensured and the residents can reach safety without any problems.

5.5 Stay-in-Place Concept

When comparing the baseline CFAST results against the long term exposure criteria, the minimum visibility was recorded at the breathing plane as 409.22m. This value is greater than the 100 meter unlimited exposure threshold. The parametric analysis further demonstrates that for the baseline atrium geometry (A_f=337.5m^2, H=7.33m), visibility stays at 469.75meters, even after 1800 seconds of continuous smoldering. From this it can be seen that the smoke density remains below dangerous levels, and the atmosphere within the traffic zones does not pose a thermal or toxic threat to the residents.

This data has an impact on the evacuation timelines simulated in Pathfinder. The simulations show that a full evacuation of the senior population is limited by available staffing levels. In case of night staffing (Simulation_2), one care assistant needs 1203.5 seconds, 20.06 minutes, to evacuate the residents, a duration that extends to 1932.6 seconds, 32.21 minutes, if movement is limited to the main groundfloor exits (Simulaiton_3.5).

Forcing a full evacuation of mobility hindered people in response to a smoldering fire introduces strategical risks and logistical strain on staff. Because the CFAST results show that the air quality satisfies the 100 meters clarity limit for unlimited exposure, an immediate evacuation is physically of toxicologically not required.

Therefore, from a results perspective, a Stay-in-Place strategy is a viable alternative for this fire scenario. With this concept, residents would remain safely inside their rooms or within adjacent protected compartments while the inside space of the atrium is monitored. This approach solves the conflict between the long required safe egress times (RSET) and prescriptive evacuation demands.

6 Discussion

6.1 Interpretation of the Experimental Findings

The experimental testing showed that the tested billiard tables behaved differently from the fire scenarios that are assumed within prescriptive fire safety regulations. Although the tables had a great amount of combustible mass, neither tested specimen transitioned into sustained flaming combustion during the observation period. Instead, both tables were kept in a smoldering state, which had a characteristic of limited mass loss, small heat release, and low thermal plume development.

This finding is important because the Dutch Building Code and other practical fire safety assessments assume that combustible objects placed in escape routes will contribute to fire growth and smoke production. The experiments show that this assumption may not always be valid when considering large composite objects such as billiard tables. Despite containing combustible materials, the combination of dense hardwood components, heavy slate playing surface, and limited fuel area creates a system with considerable thermal inertia.

The behavior suggest that the ignition source itself contributed more to the fire dynamics than the billiard table. Both test specimens showed localized charring around the ignition point, while the remaining table structure stayed unaffected. This implies that the table is more like a passive heat sink rather than an active fuel package under the tested conditions.

From a fire dynamics perspective, the presence of the slate surface appears important. The slate constantly absorbs heat from the ignition source and surrounding timber components, keeping the surface temperatures low and limiting pyrolysis. This explains why sustained flame spread across the table surface was not observed despite the long exposure to an ignition source.

These observations challenge the assumption that combustible mass alone is a reliable indicator of fire hazard. On the other hand, the arrangement of materials, thermal properties, and geometry of the object seems to be more influential than the total fuel load when assessing the ignition and growth potential of large furniture elements.

6.2 Fire Development and Smoke Production

Although the thermal hazard was found to be minimal, the experiments showed that smoke production stays the major fire safety concern in relation to billiard tables.

The thermal measurements showed maximum temperature increases of less than 1.0°C above ambient conditions. Such temperature increases are far below thresholds connected with flashover development, occupant injury, or structural damage. As a result, the traditional thermal tenability criteria, usually used in performance based design were never approached during either experimental testing or numerical modelling.

However, the absence of heat release does not automatically meant the absence of risk. Smoldering combustion can produce unusually high soot yields because combustion efficiency stays at a low level and fuel oxidation is incomplete. The experimental perception of grey smoke are consistent with this behavior.

The difference between thermal hazard and smoke hazard is important in healthcare and elderly-care environments. In such facilities, evacuation times are often lead not by fire growth but by the mobility limitations of residents. Therefore, even a low energy fire may become problematic if smoke production compromises visibility or introduces toxic gases before the evacuation process can be completed.

The current study shows that the main risk associated with a billiard table fire is therefore not thermal exposure but the degradation of environmental conditions due to smoke accumulation.

6.3 Implications of the CFAST Simulations

The simulation results support the conclusions drawn from the experimental tests. Across all geometries in the parametric analysis, gas temperatures stayed close to ambient conditions, reinforcing that the measured fire source lacks the energy needed to create a dangerous thermal environment.

This behavior can be explained through smoke dilution. The mass production rate of smoke stays constant for a given fire source. Increasing the compartment volume therefore increases the available smoke storage capacity and decreases smoke concentration. As a result, visibility becomes linked to geometric volume rather than heat release.

The parametric analysis in the research shows that the relationship between fire hazard and compartment size is especially important when evaluating safety solutions. A billiard table that may be considered problematic in a small corridor may present basically no hazard in a large atrium with substantial smoke storage capacity.

For the elderly care complex's atrium specifically, the simulation results indicate that visibility is kept well above the tenability thresholds throughout the analyzed period. Even under conservative assumptions in soot production and carbon monoxide production, the available safety margins remained substantial.

This gives the idea that the building geometry provides safety. The large volume of the atrium acts as a passive smoke reservoir, reducing smoke concentrations without the need for active intervention from smoke extraction systems.

6.4 Evaluation of the Stay-in-Place Concept

One of the main objectives of this research was to see whether the presence of a billiard table compromises the applicability of a Stay-in-Place strategy within elderly care facility.

The results show that the fire danger created by the billiard table is insufficient to support the practice of full building evacuation. Both experimental and simulation analyses show that visibility, temperature, and toxic exposure remain within acceptable limits throughout the analyzed period.

This finding is relevant because evacuation itself introduces risks in elderly care facilities. An emergency evacuation means physical and psychological stress, that can result in injuries and medical complications. As a result, a fire safety strategy should not automatically assume that evacuation is always the safest response.

Nevertheless, this conclusion should not be interpreted as a universal approval for all combustible furniture in escape routes. The findings are specific to the tested object ignition conditions, building geometry, and occupant characteristics. Different furniture types, fuel packages, or ventilation conditions could lead to completely different outcomes.

6.5 Limitations and Uncertainties

Several limitations must be considered when interpreting the results of this study.

First, the experimental test was limited to two billiard table specimens. Although both tests produced similar results, the sample size remains too small to capture the full variability that may exist between manufacturers, material compositions, ages, and maintenance conditions.

Second, direct measurements of toxic gas production were not available. Carbon monoxide and hydrogen cyanide yields where therefore estimated using conservative values. While this approach is appropriate from a fire safety engineering perspective, it introduces uncertainty into the toxic exposure calculations.

Third, the CFAST model represents the fire environment using a zone modelling approach. Such models assume that gas conditions within each zone remain spatially uniform. In reality, smoke concentrations, temperatures, and toxic gas levels may vary throughout a large atrium. As a result, localized effects cannot be captured with the same fidelity as would be possible using Computational Fluid Dynamics (CFD) tools such as FDS.

A further limitation concerns the fire scenario itself. The experiments demonstrated smoldering behavior rather than flaming combustion. While this outcome reflects the tested conditions, alternative ignition mechanisms, intentional fire setting, or involvement of additional combustible materials could generate larger heat release rates than those considered in this research.

Finally, human behavior remains one of the largest uncertainties within evacuation analysis. Pathfinder provides a representation of occupant movement, but actual resident responses can differ considerably during a real incident. Delayed recognition, confusion, staff availability, and stress induced behavioral changes are difficult to predict.

7 Conclusion and Recommendations

7.1 Conclusion

This research looked into the extent to which a billiard table located within an escape route affects evacuation safety and under which conditions its presence can be justified providing an equivalent level of fire safety.

To answer this question, a combination of laboratory fire experiments, fire and smoke simulations using CFAST, and evacuation modelling using Pathfinder were applied. The study focused on a residential care facility, where a billiard table is situated within the atrium that also functions as part of the evacuation route.

The findings show that the tested billiard tables do not behave as ordinary furniture fire. Instead of transitioning into sustained flaming, both tested specimens remained in a localized smoldering state throughout the experimental period. Mass loss stayed very limited, heat release rates stayed below 4kW, and the measured temperature increase in the surrounding environment was negligible. The fire therefore failed to generate the conditions usually associated with evacuation hazards, flashover development, or major radiant heat exposure. Experimental observations indicated as well, that the heavy slate playing surface and the large thermal mass of the construction act as a heat sink, limits fire growth and flame spread.

The Pathfinder analysis showed that the Required Safe Egress Time (RSET) stays shorter than the Available Safe Egress Time (ASET) for all occupant categories. This result is important given the vulnerability of the resident population. The evacuation of elderly occupants often needs staff assistance and can have the risk of medical or logistical problems. As a result, evacuation does not mean the safest strategy. Instead, the results indicate that residents can stay within protected zones, while only evacuating the near surroundings of the fire area is necessary. This provides a safer response to a localized billiard table fire.

Sub-Question 1:

What fire safety performance criteria are relevant for assessing evacuation safety in senior housing?

From the research it can be concluded that visibility, toxic smoke exposure and thermal exposure are the most relevant performance indicators when assessing evacuation safety in senior housing. Due to the reduced mobility and increased vulnerability of elderly residents, conservative tenability limits were adopted for visibility and thermal radiation. Out of these criteria, visibility proved to be the most important factor. Thermal conditions stayed negligible throughout all simulations. As a result, visibility reduction due to smoke is the main parameter that needs evaluation for this type of fire scenario.

Sub-Question 2:

What are the fire characteristics of a traditional billiard table, and how do material variations influence these?

The experiments showed that traditional billiard tables have low fire growth potential under the tested ignition conditions. Both tested tables had minimal mass loss, remained in smoldering state, and generated heat release rates below 4kW. Differences in frame construction and geometry showed only small variations in mass loss and fire behavior. The results therefore imply that the overall construction, especially the combination of timber components and the slate playing surface, has a greater influence on fire development than small variations in table design.

Sub-Question 3:

How does the presence of a billiard table fire affect the ASET in a typical atrium building compared to the RSET of vulnerable occupants?

The impact of a billiard table fire on ASET is limited. The low heat release rate prevents the development of hazardous thermal conditions, while smoke production stays insufficient to reduce visibility below accepted thresholds within the investigated atrium geometries. So, ASET is much longer than the evacuation times calculated for the residents. This relationship was maintained throughout both the baseline scenario and the parametric analysis, resulting in a great safety margin between available and required evacuation time. Visibility and thermal exposure remain within the accepted tenability limits.

Sub-Question 4:

Can a Stay-in-Place strategy provide a higher level of safety than total evacuation in the event of a localized furniture fire in an escape route?

The investigated scenario suggests that Stay-in-Place may be a reasonable strategy for localized shouldering billiard table fires in large-volume compartmented care facilities. Because the fire stays localized and does not generate dangerous thermal or smoke conditions within the wider building, the risks associated with moving fragile residents may exceed the risks posed by the fire itself. Under these conditions, selective evacuation of the affected area combined with sheltering of residents in protected compartments represents a justified safety strategy.

Main Research Question

To what extent does a billiard table placed in a residential escape route affect evacuation safety, and under which conditions can its presence be justified as providing equivalent fire safety according to Dutch building regulations?

It can be concluded that a traditional billiard table has a limited impact on evacuation safety when located within a large-volume residential atrium. The tested billiard tables did not show sustained flaming combustion, generated negligible fire hazards, and produced insufficient smoke to compromise tenability within the analyzed building setup. As a result, the presence of a billiard table can be justified as providing an equivalent level of fire safety when performance based assessment shows that:

The fire stays at a low-intensity smoldering scenario

Visibility, toxic exposure and thermal exposure remain within accepted tenability limits

ASET remains greater than RSET with sufficient safety margin

Compartmentation and operational procedures support a Stay-in-Place strategy, and

The specific building geometry provides sufficient smoke dilution and storage capacity

Smoke alarms should be present at every floor height to ensure early detection of smoke

Under these conditions, the presence of a billiard table in a residential escape route does not result in an increase in fire risk and may therefore be considered compatible with the Dutch Prescriptive Regulations based on the equivalent safety principle.

7.2 Recommendations

Based on the findings of this research, several recommendation can be made for practice, policy and future research.

7.2.1 Recommendations for Practice

When assessing combustible objects in residential escape routes, authorities and fire safety consultants should evaluate the fire behavior of the object rather than relying on its combustible mass. Large composite objects with substantial thermal inertia may present lower fire hazards than usually assumed.

For healthcare and elderly home facilities, evacuation strategies should consider the risks associated with moving vulnerable occupants. Performance-based assessments should compare evacuation risks against realistic fire consequences rather than assuming that immediate total evacuation is always the safest option.

Where billiard tables or similar furniture are present in communal atria, a building specific performance based assessment should be conducted to verify that ASET exceeds RSET and that visibility stays above the required thresholds.

7.2.2 Recommendations for Future Research

Multiple opportunities exist to strengthen the evidence found in this research.

Future research should investigate a larger range of billiard table configurations and furniture types commonly found within communal care facility spaces. This would allow the development of a broader classification framework for combustible objects in escape routes.

Additional experimental work should focus on direct measurement of smoke yields, carbon monoxide production, and hydrogen cyanide generation. Such measurements would reduce uncertainty in tenability assessments and make the performance-based modelling more reliable.

From another perspective, CFD simulations using Fire Dynamics Simulator (FDS) could be conducted to see smoke stratification and localized visibility conditions within large atria. While the present study demonstrates that CFAST is suitable for screening analyses, CFD modelling could provide additional confidence in the findings.

Finally, future studies should further examine the interaction between fire safety strategy and resident vulnerability. In healthcare environments, the decision between evacuation and sheltering is influenced as much by human factors as by fire dynamics. Developing methods for balancing these risks would improve performance-based fire safety design for senior facilities.

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References

[1] Drysdale, D. (2011). An Introduction to Fire Dynamics (3rd Edition). University of Edinburgh, Scotland, UK: John Wiley & Sons.

[2] Quintiere, J. (2006). Fundamentals of Fire Phenomena. University of Maryland, USA: John Wiley & Sons.

[3] Boverket. (2011). BBRAD: Boverkets allmänna råd om analytisk dimensionering av byggnaders brandskydd. Karlskrona: Boverket.

[4] van Herpen, R. (2023). 7LY4M0 Fire Safety Engineering Lecture Notes. Eindhoven University of Technology.

[5] Karlsson, B., & Quintiere, J. (2000). Enclosure Fire Dynamics. Florida, U.S.: CRC Press LLC.

[6] Brandweer Nederland. (2020). Handrekening Brandveilig Gebruik van Vluchtroutes

[7] Babrauskas, V., & Grayson, S. (1992). Heat Release in Fires. Barking: Elsevier Applied Science.

[8] Hurley, M. J. (Ed.). (2016). SFPE Handbook of Fire Protection Engineering (5th Edition). Society of Fire Protection Engineers: Springer.

[9] ISO 13571:2012. Life-threatening components of fire — Guidelines for the estimation of time to compromised tenability in fires.

[10] C. Postuma, Het Biljartspel in Nederland: Een Cultuurhistorische Analyse, Amsterdam: De Bataafsche Leeuw, 1992.

[11] N. Shamos, The Illustrated Encyclopedia of Billiards, New York: Lyons & Burford, 1993.

[12] Wilhelmina Biljarts, "Technical Specifications: Heating and Construction of Match Tables," Amsterdam, Internal Document, 2023.

[13] R. van Herpen, Brandveiligheid in de Zorg: Een verschuiving naar gelijkwaardigheid, Eindhoven: TU/e, 2021.

[14] Koninklijke Nederlandse Biljartbond (KNBB), "Reglementen betreffende de uitrusting en materialen," [Online]. Available: https://www.knbb.nl. [Accessed: 05-May-2024].

[15] EN 1995-1-2: Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design, Brussels: CEN, 2004.

[16] D. Drysdale, An Introduction to Fire Dynamics, 3rd ed. Chichester: John Wiley & Sons, 2011.

[17] J. G. Quintiere, Fundamentals of Fire Phenomena, West Sussex: John Wiley & Sons, 2006.

[18] V. Babrauskas, Ignition Handbook, Issaquah, WA: Fire Science Publishers, 2003.

[19] M. J. Hurley (Ed.), SFPE Handbook of Fire Protection Engineering, 5th ed. New York: Springer, 2016.

[20] Van den Broek Biljarts, "Insulated heating wire: Technical Specifications and Energy Consumption," Amsterdam, Technical Data Sheet, 2024.

[21] Hunt, Aoife, Edwin R. Galea, and Peter J. Lawrence. 2013. “An Analysis and Numerical Simulation of the Performance of Trained Hospital Staff Using Movement Assist Devices to Evacuate People with Reduced Mobility.” Fire and Materials 39 (4): 407–29. https://doi.org/10.1002/fam.2215.

[22] G. Baker, "Electrical Ignition of Furniture and Floor Coverings," Fire Technology, vol. 42, no. 1, pp. 27–45, 2006.

[23] V. Babrauskas, "The effects of aging on the flammability of polymers," Fire and Materials, vol. 31, no. 4, pp. 243–260, 2007.

[24] R. van Herpen, "De invloed van onderhoudsproducten op de brandbaarheid van houten meubilair," TU/e Internal Publication, 2019.

[25] A. Lönnermark and H. Ingason, "Fire Development and Smoke Production in Large Atriums," RISE Report, 2010.

[26] J. Magyar, "The History and Evolution of Karambol Billiards in Central Europe," Journal of Sporting History, vol. 14, no. 2, 2015.

[27] G. Heskestad, "Fire Plumes, Flame Height, and Air Entrainment," in SFPE Handbook of Fire Protection Engineering, 5th ed., New York: Springer, 2016.

[28] B. Karlsson and J. G. Quintiere, Enclosure Fire Dynamics, Boca Raton: CRC Press, 2000.

[29] N. McConnell and K. Boyce, "The evacuation of the elderly and those with disabilities," Fire Safety Journal, vol. 32, no. 3, pp. 201–214, 1999.

[30] R. van Herpen, "Stay-in-place principle for vulnerable people: A fire safety engineering approach," Journal of Building Engineering, vol. 45, 2022.

[31] R. D. Peacock, K. B. McGrattan, G. P. Forney, and P. A. Reneke, CFAST - Consolidated Model of Fire Growth and Smoke Transport (Version 7) Technical Reference Manual, NIST Special Publication 1026, National Institute of Standards and Technology, Gaithersburg, MD, 2021.

[32] Thunderhead Engineering, Pathfinder Technical Reference Manual (Version 2025.1), Manhattan, KS: Thunderhead Engineering, 2025.

[33] Heat transfer. (n.d.). https://physicspractice.blogspot.com/2009/03/heat-transfer.html

[34] van Herpen, R. (2023). 2. Natural fires. Eindhoven University of Technology: 7LY4M0 Fire Safety.

[35] S. Drost, "Onderzoek vluchtveiligheid atrium - De Lange Wei," Deerns Nederland B.V., Rijswijk, Technical Memorandum RNL.160.06713.00.0100, Nov. 2025.

Appendix

Appendix A - Literature Review

In this literature review the scientific principles needed to evaluate the fire risk of localized fire loads in escape spaces. It will begin with he core principles of fire dynamics, in order to understand how complicated objects, such as billiard tables that have multiple materials behave during ignition. After this the review will continue with the mechanism of heat and smoke transport in large volumes, such as atriums, and conclude with the specific composition of materials of one of the tested billiard tables.

A.1 Fundamentals of Fire Dynamics

Fire dynamics is the study of how chemistry, fluid mechanics, and heat transfer interact to influence fire behaviour [1]. In the context of this research, it is important to understand these principles to see beyond the prescriptive no-tolerance approach of the Dutch Bbl. By analysing the physical processes of a billiard table fire, it becomes possible to quantify the risk that is posed to residents in escape routes. [2]

A.1.1 The Combustion Process

Combustion is an exothermic reaction that requires fuel, oxidizing agent and heat. This is usually represented by the fire triangle (see Figure 17). For the billiard table, this process becomes more complex because of its material composition. Initial ignition is most likely to occur in the synthetic wool felt covering [19], which has a high surface to volume ratio. As the fire continues, the heat release can be continued by the vulcanized rubber cushion and the high density hardwood frame later. Whether the transition from localized flaming to sustained fire occurs depends heavily on the released energy. This has to be enough to overcome the thermal inertia of the heavier components. [1]

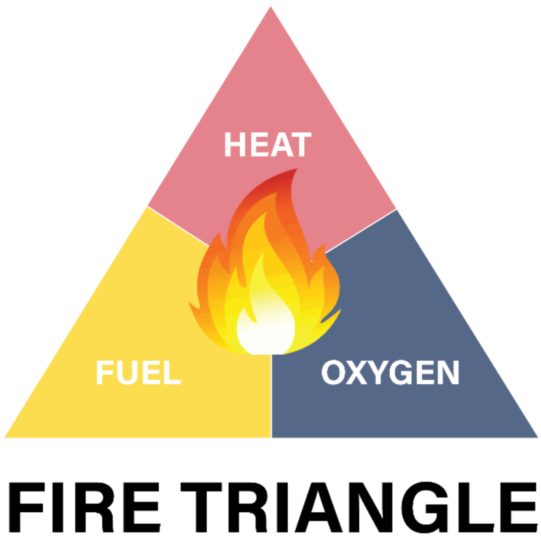


Figure 17: Fire Triangle

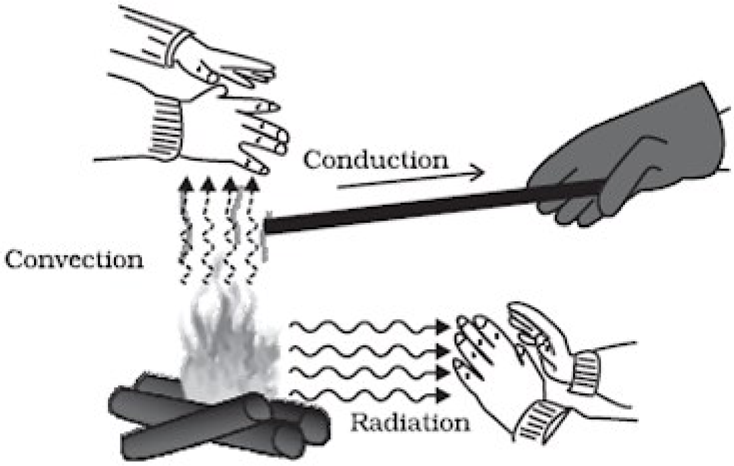


Figure 18: Heat Transfer Mechanisms [33]

A.1.2 Heat Transfer Mechanisms

Fire spread and its impacts on occupants can occur in three main mechanisms.

Conduction is significant for the internal heating of the hardwood frame and the slate bed. While the slate absorbs a lot of heat, the wood frame eventually can contribute to the total fire load as its temperature goes over the ignition threshold. [2]

Convection in an atrium setting is the main transport mode for smoke. Hot gases rise in the buoyant plume, which fill the 10.79 meter volume from the top down. The smoke filling the atrium process is directly linked to the Available Safe Egress Time (ASET). [5]

Radiation for an escape route is the most critical hazard for vulnerable residents. Elderly skin sensitivity makes radiant heat flux, even at levels below 2.5 kW/m^2, a significant barrier for evacuation. Radiation also carries the probability of ignition of nearby combustible items, potentially making a single object fire into a larger compartment fire. [1]

A.1.3 Stages of Fire Development

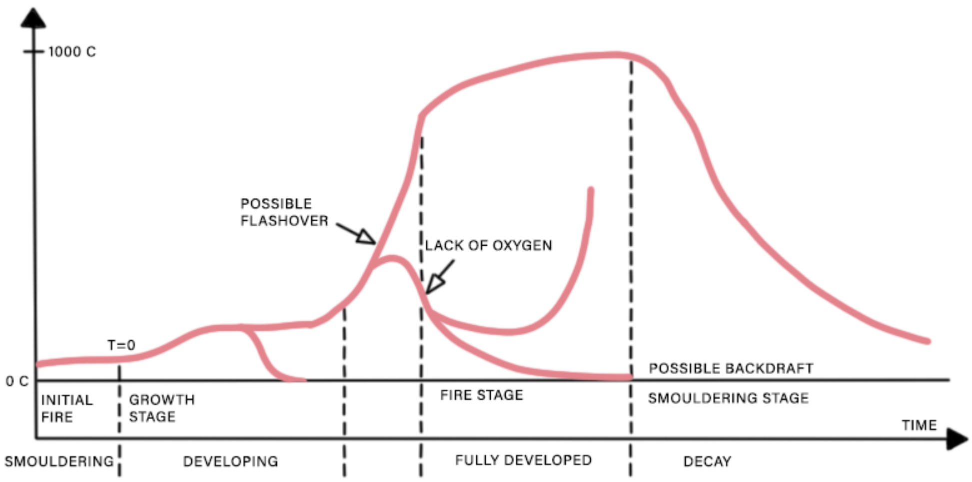


Figure 19: Fire Curve [34]

A furniture fire usually follows four stages: ignition, growth, the fully developed phase, and decay [4].

The ignition and growth phases are the most critical ones for this study. The t-squared (t^2) fire growth model is often used to characterize how quickly a billiard table gets to its maximum Heat Release Rate (HRR).

Flashover is common in small rooms and is less likely to occur in a 10.79 meter atrium because the large volume and cooling effects. Instead of the flashover condition the primary threat is the descent of the smoke layer to a height where it disturbs the visibility and breathing (tenability limits) [5].

Decay happens when all fuel is consumed, though smouldering in the deep hardwood can continue to produce toxic gases long after the flaming phase ends.

A.1.4 Key Fire Dynamics Parameters

To assess Equivalent Safety, multiple measurable parameters must be measured:

The Heat Release Rate (HRR) is considered the only most important parameter in fire safety engineering [7]. It's main function is to define the fire's power and it determines the speed of smoke production.

Smoke and toxic yield quantifies the production of soot, which impacts visibility, and gases like CO, which impacts the Fractional Effective Dose (FED).

The Mass Loss Rate (MLR) indicates the rate at which the solid fuel, wood and rubber, are converted to gaseous fuel, providing further cross reference for the HRR [7].

A.1.5 Fundamentals of Fire Safety Engineering (FSE)

Fire safety engineering shifts the focus from what a building is made of to how it performs during an emergency [8]. This performance based way is used here to bridge the gap between social requirements (the presence of the billiard table) and life safety.

A.2 The Billiard Table

Billiards, especially the carambole variant, has a unique position in Dutch social history. Since the late 19th century, the billiard table went from being the game of the elite to a cornerstone of the “bruin café” culture and communal spaces in the Netherlands. [10] In the context of senior housing and residential buildings with an atrium, the tables are not simply furniture but represent the social aspect that makes cognitive involvement and community bonding possible.

A.2.1 Evolution in the Dutch Context

The development of the modern billiard table was influenced by Dutch craftmanship, mostly by manufacturers like Wilhelmina Biljarts (est. 1898). Historically, the tables started out as simple wooden planks and evolved into sophisticated composite structures. An important turning point was the introduction of the Italian slate bed around the mid-1800s, which replaced the wooden beds that could be easily warped. [11] This change increased the non-combustible mass of the tables, but at the same time made them heavier, more robust than timber frames.

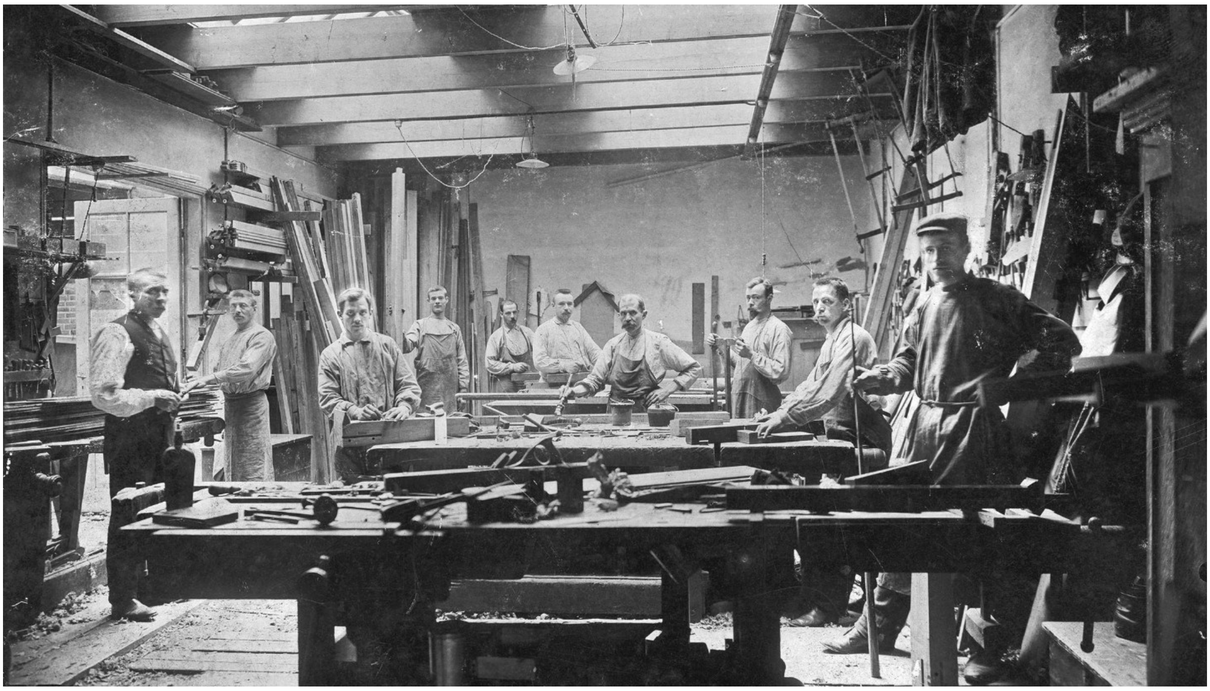


Figure 20: Wilhelmina Biljarts table production in Amsterdam (Perfecte Biljarts, 2024)

Nowadays in senior care facilities and residential complexes, the presence of these tables can be connected to the legacy of the club culture. However, while the social value of the tables remains constant, the materialization has become more complex and changed a lot over time. This change involves synthetic blends, electrical heating systems that were not present in earlier versions. [26]

A.3 Classification: The Carambole Billiard

The specific type of table dealt with in this research is the Carambole billiard table. Unlike normal billiard tables, which have six pockets, the carambole table is pocketless and relies only on the rebound physics of the balls against the rubber cushions at the sides.

A.3.1 Technical Specifications

Carambole tables in the Netherlands usually fall into two categories: the Match table (Groot biljart) and the Club table (Klein biljart).

The match table has a playing surface of 2.84 x 1.42 meters, while the club tables, which are more commonly found in residential settings, have a surface of 2.10 x 1.05 meters or 2.30 x 1.15 meters [14].

An important technical part of Dutch carambole tables is the usage of an internal heating system. The electrical elements, usually rated at 100W, are situated below the slate and their purpose is to support maintaining the surface temperature of approximately 35°C to 40°C. This minimizes the moisture in the cloth to ensure a steady roll [26]. From a fire safety perspective, this system poses a permanent electrical ignition source directly in contact with combustible timber and felt. This is what makes the billiard table different from furniture like wardrobes and chairs.

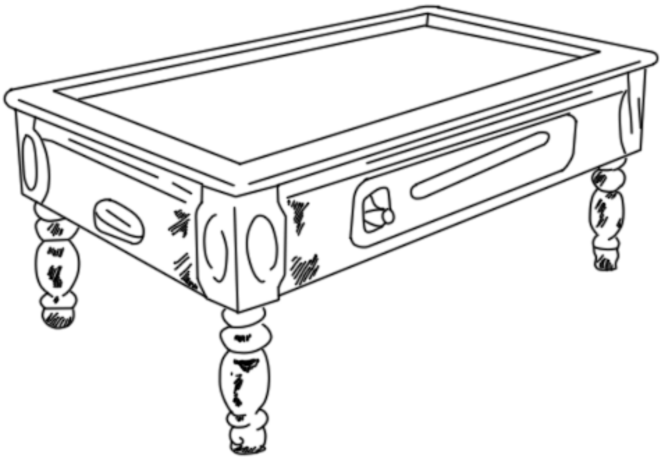


Figure 21:Line Drawing of Carambole Billiard Table

A.4 Characteristics of Materials

To quantify the fire risk, the billiard table has to be seen as a composite fuel package. Every component contributes differently to the ignition, growth and smoke production phases of a fire.

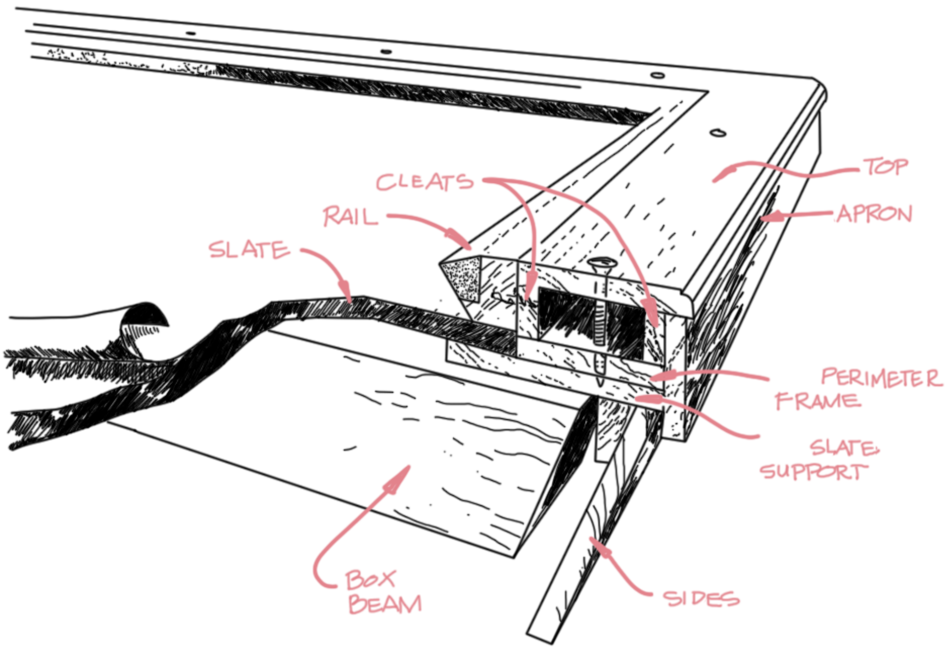


Figure 22: Section of a Billiard Table shown as a Composite Fuel Package

A.4.1 The Timber Sub-Frame and Legs

The main fuel load is the timber frame, usually made from high density hardwoods, like Oak, Mahogany, or Maple. These materials are thermally thick solids. According to Eurocode 5 (EN 1995-1-2), hardwoods have a standard charring rate of around 0.5 mm/min. [15] The 6 pole leg configuration is quite an interesting set-up for such a table, as it has a high surface to volume ratio, because of the individual legs, compared to solid block designs. It also allows for faster absorption and earlier ignition of the vertical members, which can then grow into a sustained flame. [16]

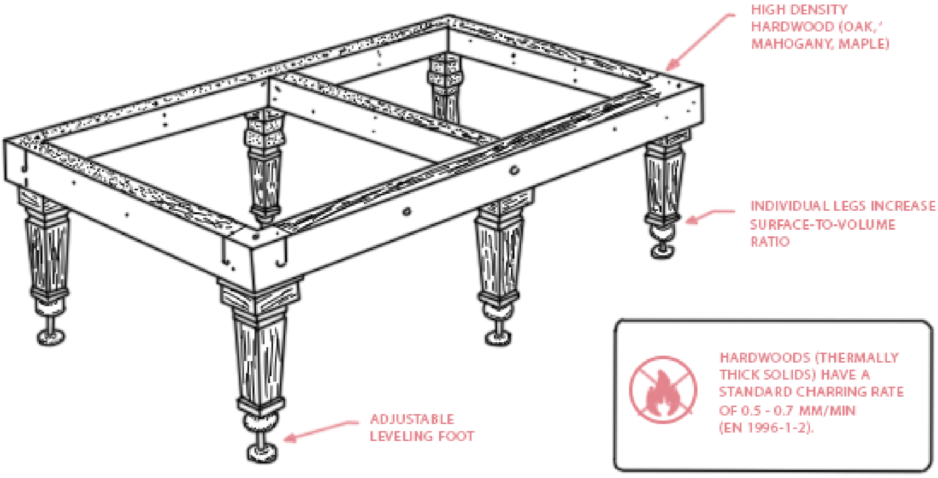


Figure 23: Drawing of the Timber Sub-Frame and Legs

A.4.2 Slate, the Playing Surface

The playing surface is a slate, a metamorphic rock that is mostly made up of quartz or stone. The slate is non-combustible, it has an important role in the fire dynamics as it is a massive heat sink. During the growth phase, the slate absorbs and accumulates a great amount of the convective and radiant heat, which may at first slow down the fire spread across the top of the table. However, as soon as the slate reaches a sufficiently high temperature, it contributes to the oven effect, prolonging the decay phase and helping in maintaining high temperatures in the timber that is around, even after the flames have gone out. [7]

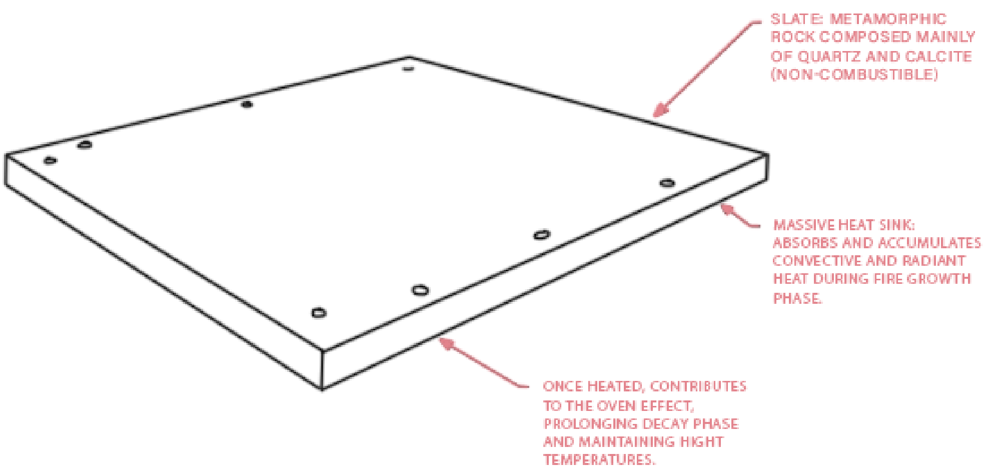


Figure 24: Drawing of the Slate

A.4.3 Vulcanized Rubber Cushions

The cushions are made from vulcanized rubber, a thermoset polymer what includes sulphur. This part is the main contributor to smoke toxicity and soot yield. Rubber has a high heat of combustion (25-30 MJ/kg) and can produce thick, black smoke that quickly reduces visibility [18]. In an atrium setting, the soot yield from these rubber components is the factor that has the highest likeliness of blocking the 10 meter visibility, that is set by the BBRAD for residents.

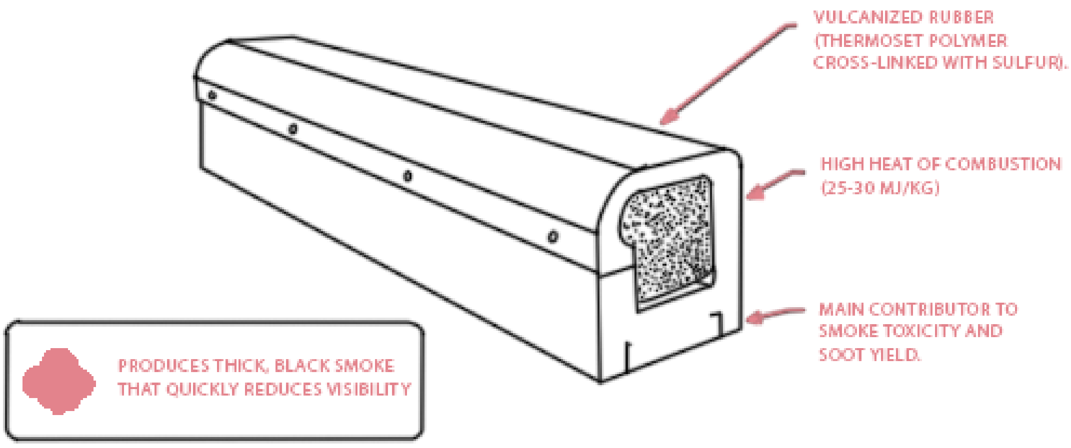


Figure 25: Drawing of the Vulcanized Rubber Cushions

A.4.4 Felt

The Simonis cloth, is usually 90% wool and 10% nylon, covers the slate and cushions parts of the billiard table. Wool is flame resistant but because of its high nitrogen and moisture content, the synthetic nylon part and the fibres with a great surface area allow for a flame spread [19]. This flash over the surface can in short time involve the rubber cushions, leading to the release of toxic gases like Hydrogen Cyanide(HCN) and Carbon Monoxide (CO).

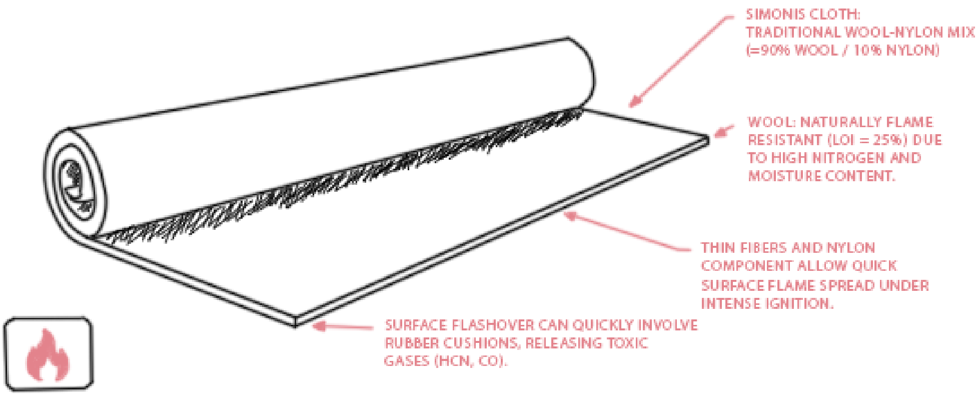


Figure 26: Drawing of the Felt

A.5 The Electrical Subsystem

While the majority of furniture is considered a passive fire load, the carambole is an active electronic device. To achieve the quality required for professional play, moisture must be closely controlled within the cloth fibres.

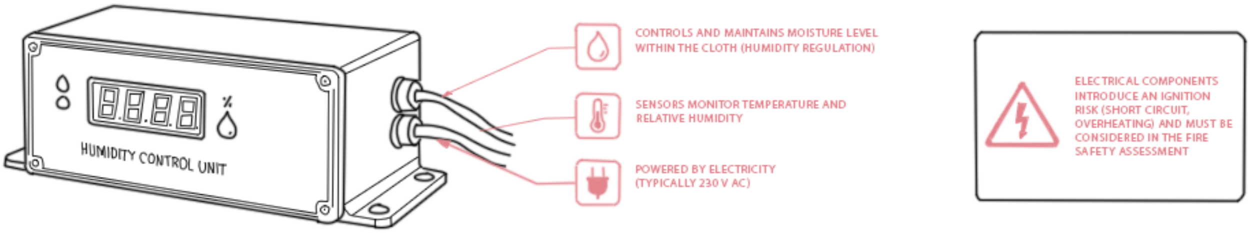


Figure 27: Drawing of the Electric Heating Component

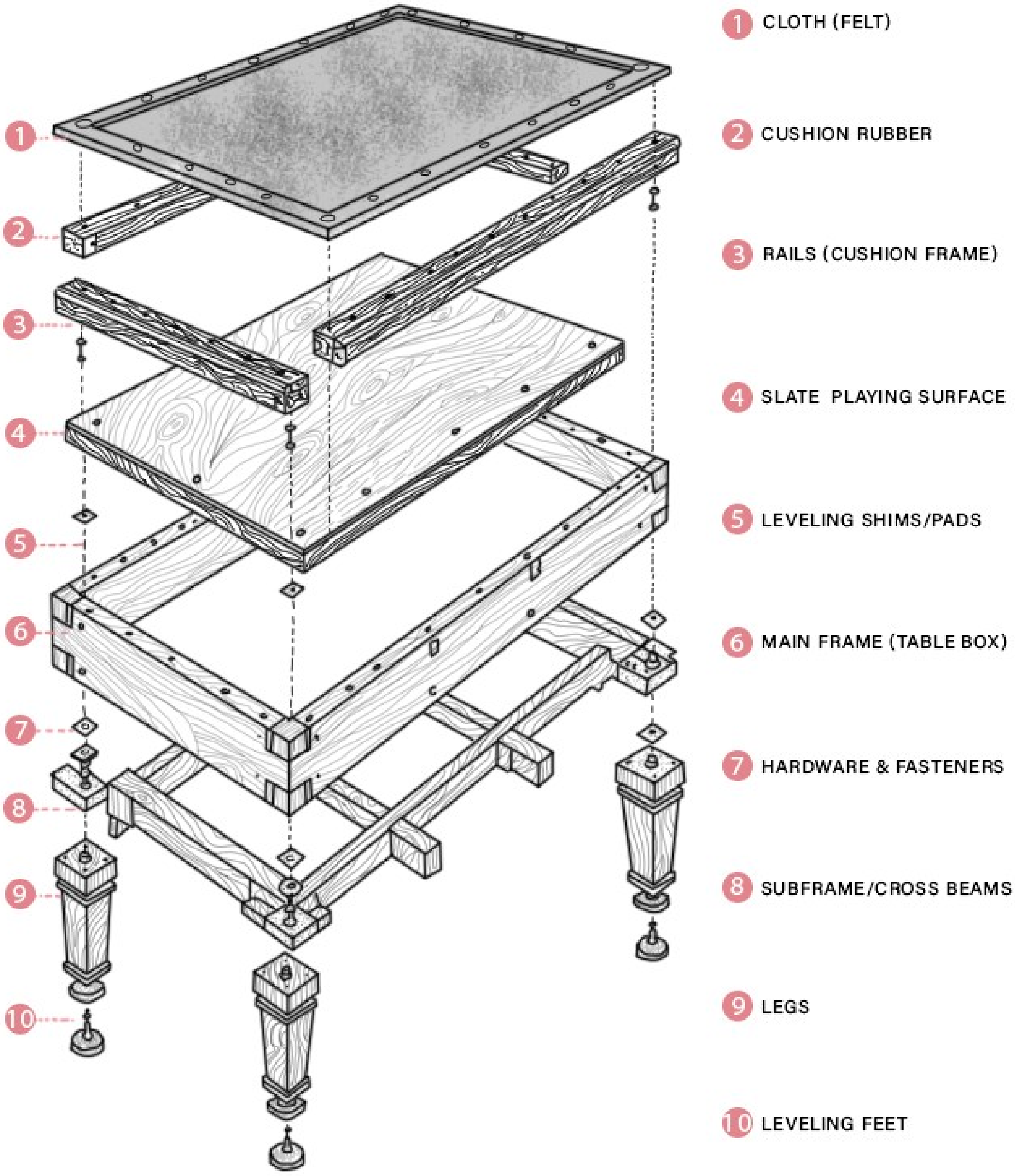


Figure 28: Exploded View of a Typical Carambole Billiard Table and the name of its Components

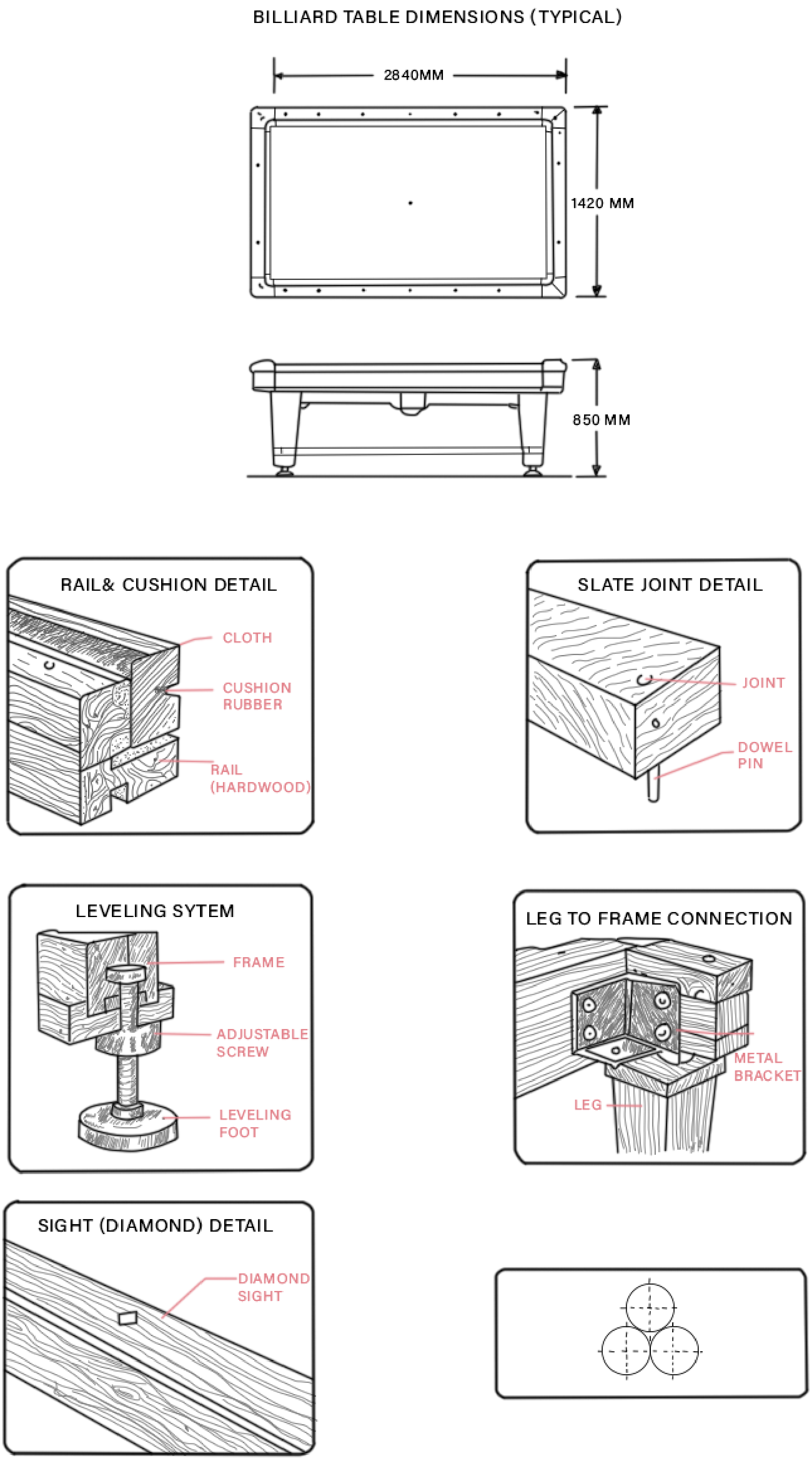


Figure 29: Dimensions and Details of a Typical Carambole Billiard Table

A.5.1 Heating and Thermal Conditioning

Modern carambole tables use a sandwich heating construction placed right below the slate. This typically consists of:

The base layer, a moisture resistant MDF or plywood carrier board. An insulation, which is foil-backed (around 25 mm) to reflect heat upwards. And an active element, which are silicone protected resistance wires (usually 1.46 Ohm/meter) or ceramic heating plates. [20]

The system usually operates at 100W, keeping the table 3°C to 5°C above the ambient room temperature. From a fire safety perspective this generates a constant heat source in direct contact with a pre-heated fuel bed. If the component fails, the temperature of the timber sub-frame can get close to it's ignition point, 250°C-300°C, significantly reducing the energy needed for a secondary source (e.g., a dropped cigarette or electrical short circuit) to initiate a fire [22].

A.6 Material Aging

The fire hazard of a billiard table is not constant, it changes over its 50- to 100-years lifecycle. This aging effect is quite relevant in senior housing and residential housing where many tables are decades old.

A.6.1 Rubber Vulcanization and Hardening

The vulcanized rubber cushions contain chemical plasticizers and filler such as clay or silica. Over time, and further accelerated by the table's internal heating, the cushions oxidize. Natural rubber becomes more brittle and it loses its elasticity in 10 to 12 years if often repeatedly heated. [20] In such a state, the rubber starts to crack, which enlarge the effective surfaces for ignition. Furthermore, the soot yield and the production of Carbon Monoxide (CO) can differ as the polymer chains break down. It can possibly lead to more quick production in an older table compared to a brand new one.[23]

A.6.2 Maintenance and Flammability

The maintenance of the timber frame and the Simonis cloth, involves the use of special oils, waxes and cleaning sprays. Traditional Dutch tables were often finished with linseed oil-based varnishes or waxes to protect the hardwood. These finishes, especially if just applied, can act as accelerators, which help with a faster surface flame spread over the table, before the thermally thick hardwood core would be involved. [24]

A.7 Sustainability and the Fire Load

Looking at the trends in bio-based construction, the billiard industry is shifting toward more sustainable material usage, which changes the fire profile.

A.7.1 Solid Wood and Engineered Composites

Historically, producers such as Wilhelmina Biljarts used solid mahogany or oak. In recent years, however, there has been a shift towards high density fibreboards (HDF) or MDF for recreational tables to reduce costs and environmental impact. While the charring of solid wood can be predicted, MDF has large amounts of urea-formaldehyde resins. During combustion, these resins can let out bigger concentrations of nitrogen based toxic gases, which impacts the Fractional Effective Dose (FED) calculations for the ASET/RSET analysis. [25]

A.8 Plume Dynamics and Atrium Effect

The fire risk of a billiard table can only be assessed in context. Its impact is linked to the volume of the space. In a high atrium, the interaction between the localized fire plume and the surrounding air follows specific fluid dynamic principles.

A.8.1 Point Source and Area Source Plumes

In the initial growth phase, a billiard table is expected to behave as a localized point source. As the fire spreads across the 2 to 3 square meter of surface of the cloth and rubber, it is expected to transition into an area source. According to the Heskestad plume model, the mass flow rate of smoke is heavily dependent on the entrainment of cold air from the atrium flow. [27] Because the billiard table is elevated on legs (6 or 4 pole design), air can be entrained from underneath the fuel bed as well as from the sides. This unrestricted entrainment can cause more effective combustion, but also a larger volume of smoke compared to fire on a flat floor. [28]

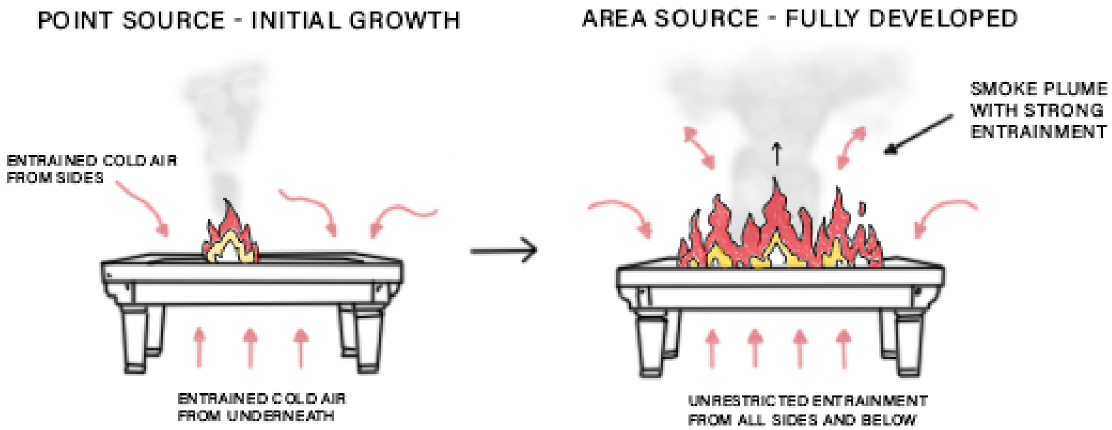


Figure 30: Point Source and Area Source Plumes

A.8.2 Smoke Layer Buoyancy and Cooling

In large volumes, the smoke plume loses temperature as it rises due to the entrainment of ambient air. If the Heat Release Rate (HRR) of the table is too low, the smoke may lose its buoyancy before reaching the highest point of the ceiling, resulting in a stratification effect where smoke hangs at mid-height, the breathing zone of residents on upper galleries. [28] This detail can be important for the CFAST simulations, as it can determine whether the Equivalent Safety is compromised by the descending smoke layer or by localized visibility loss.

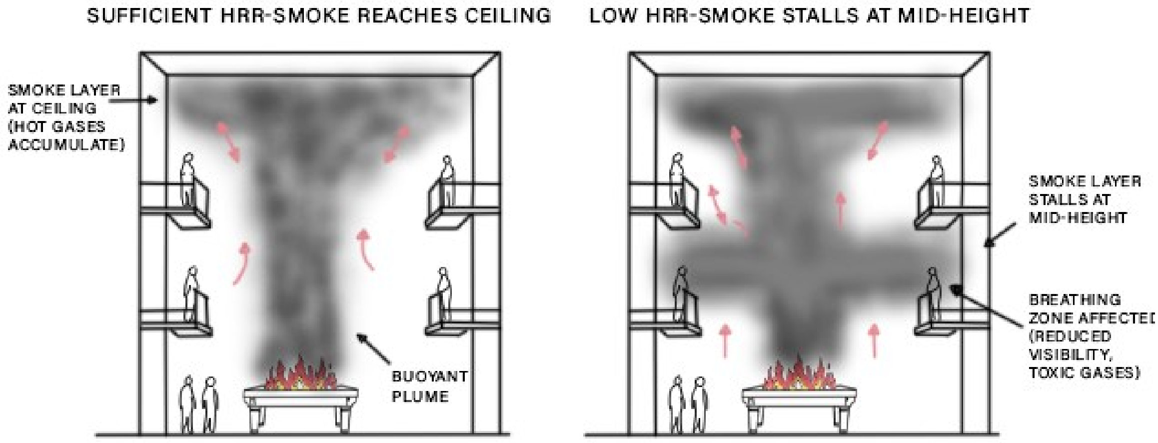


Figure 31: Smoke Layer Buoyancy and Cooling

A.9 The Vulnerability Perception

While the BBRAD gives certain horizontal walking speeds, it does not completely address the human factor, barriers specific to senior housing environments.

A.9.1 Stay-in-Place and Complete Evacuation Strategy

At the moment the Dutch safety strategies slowly start recognizing that total evacuation might not always be necessary, but the Stay-in-Place concept can also be used for healthcare or residential functions. The readings suggest that for residents with dementia or physical impairments, the stress of evacuation can be more life-threatening than the fire itself. [29] A billiard table in an escape route poses a difficult question: if the fire is localized, is it safer to move more than 20 seniors past the fire (risking radiation and panic) or to keep them in their fire-rated rooms? [30]

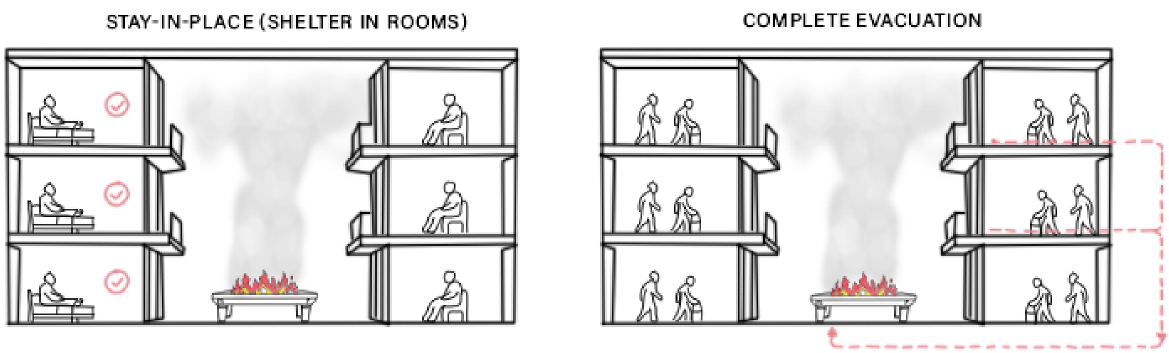


Figure 32: Stay-In-Place and Complete Evacuation Strategy

Appendix B – Floorplans and Sections of a Senior Housing Complex

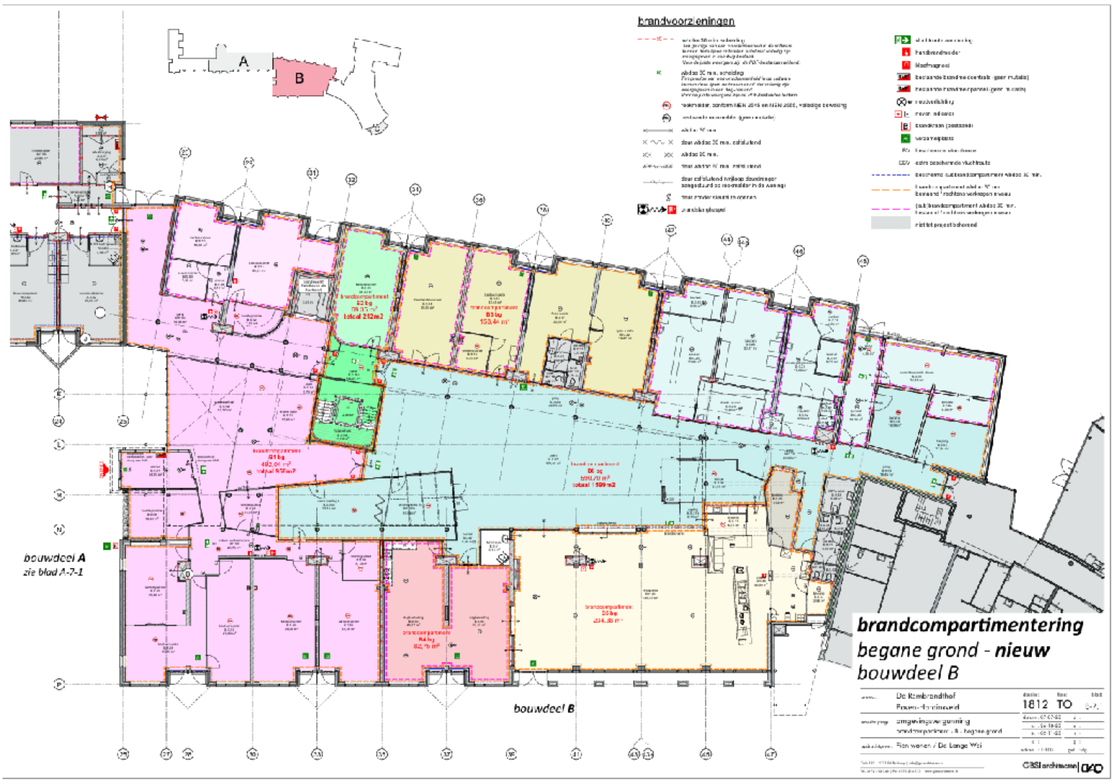


Figure 33: Ground Floor Floorplan of a Senior Housing Complex

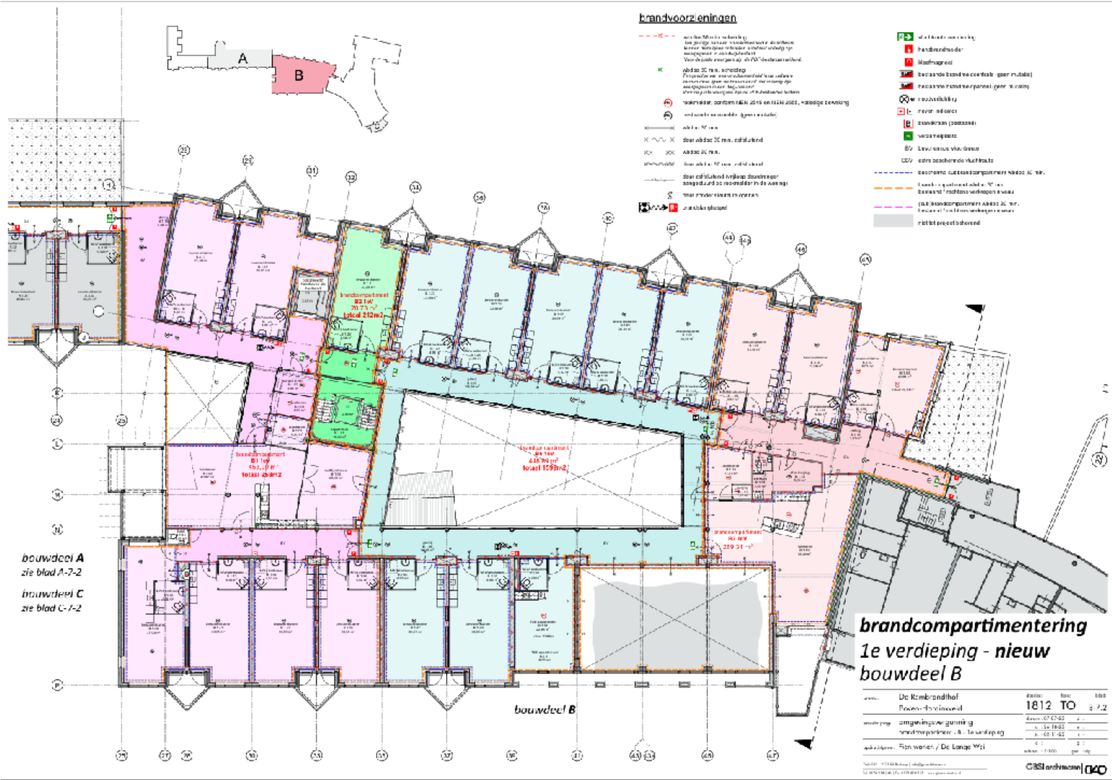


Figure 34: 1st Floor Floorplan of a Senior Housing Complex

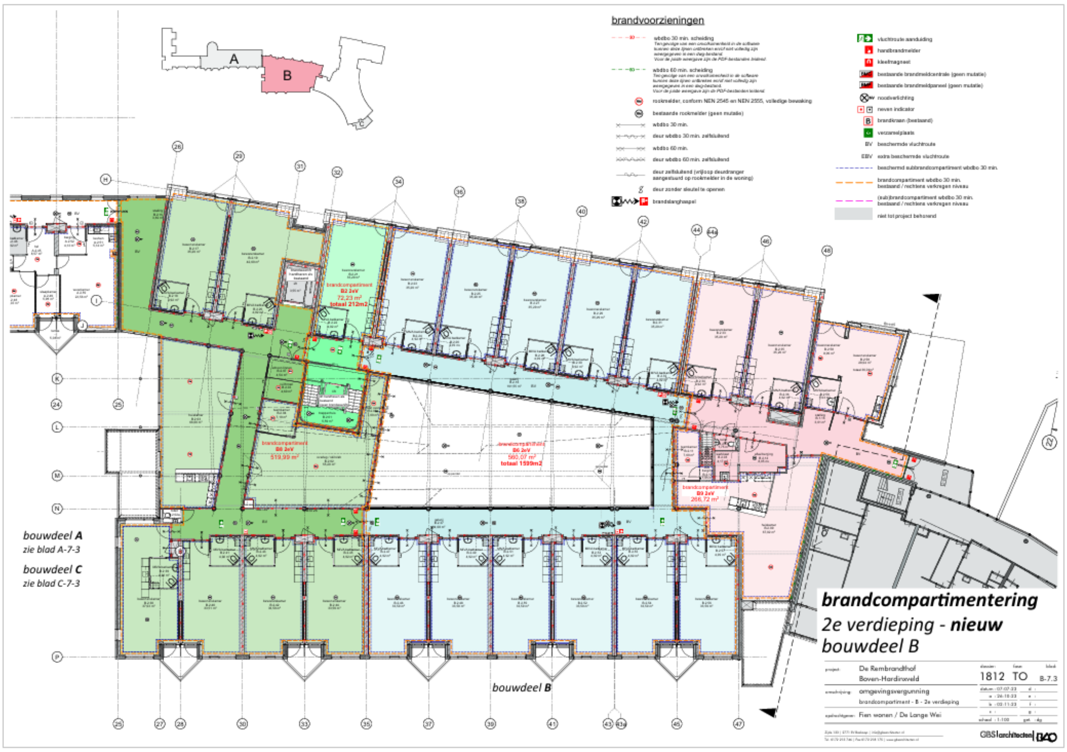


Figure 35: 2nd Floor Floorplan of a Senior Housing Complex

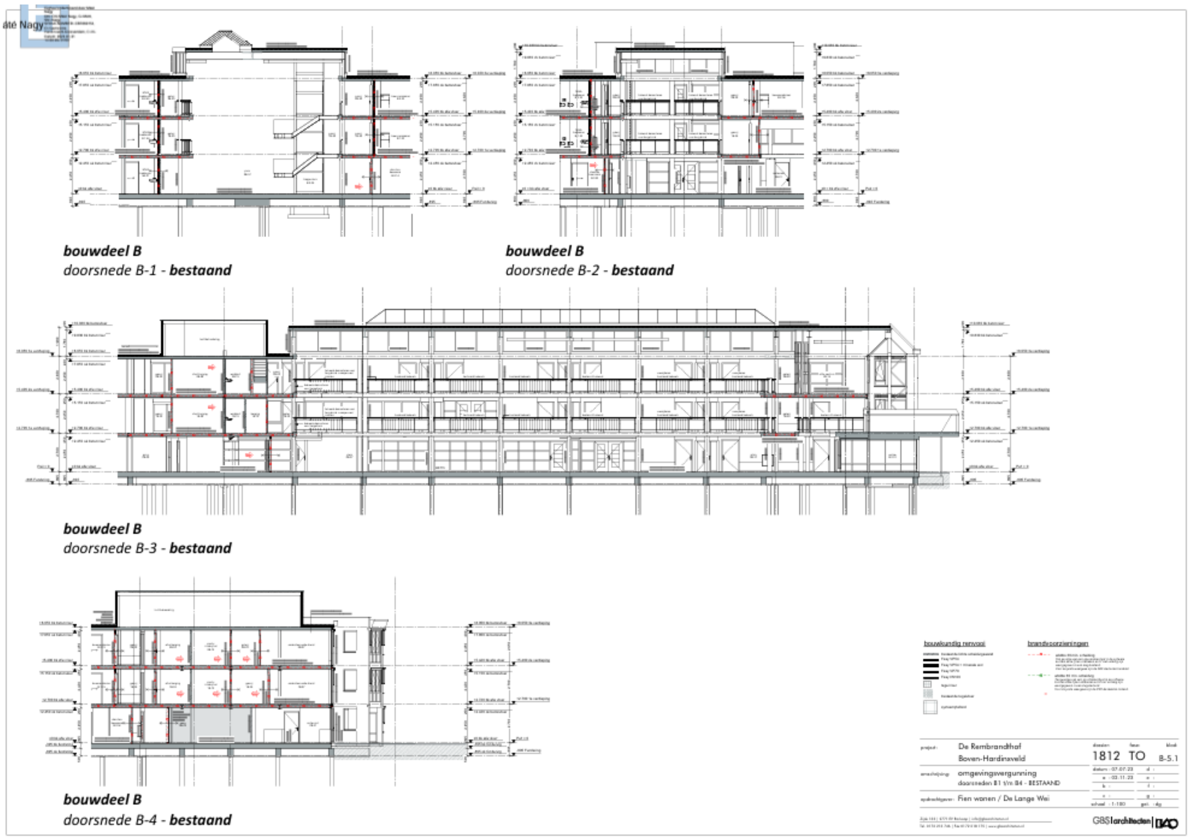


Figure 36: Sections of a Senior Housing Complex

Figure 37: Sections of a Senior Housing Complex

Appendix C – Elderly Home Atrium

Figure 38: Picture of the Atrium of a Senior Housing Complex

Appendix D – Table 1 Experimental Testing

Figure 39: Table 1 of the Experimental Testing

Figure 40: Ignition start of Wooden Crib (left) and Smoke Beginning to Form during Testing (right)

Figure 41: Smoke Beginning to Form (right) and Fire Inside the Table (left)

Figure 42: Final State of Smoke and Visibility in the Testing Zone

Figure 43: Material Loss of Table (left) and Charring of Wooden Components (right)

Figure 44: Charring of Table Components

Appendix E -Table 2 Experimental Testing

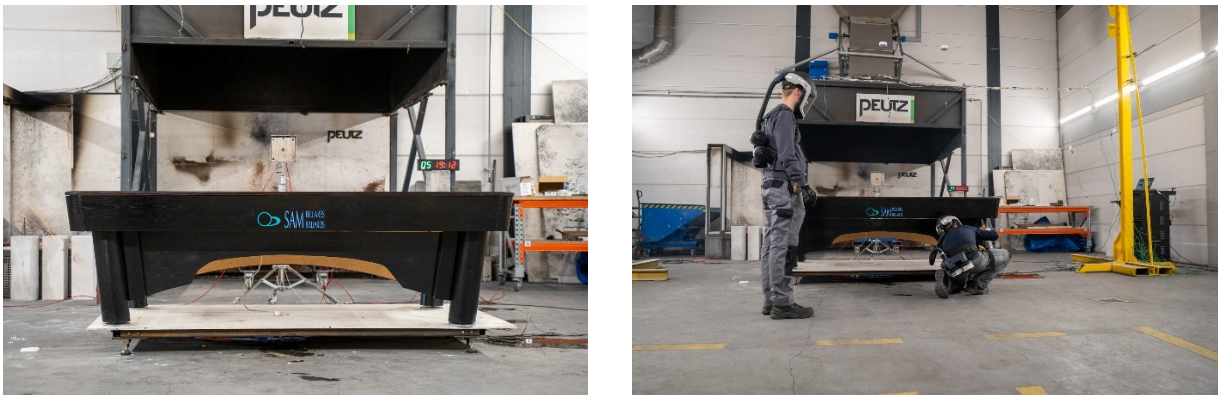


Figure 45: Table 2 of the Experimental Testing (left) and 2nd Attempt to Bring Table 2 into Flames (right)

Figure 46: 3rd Attempt to Bring Table 2 into Flames (left) and Taking out Table Fire 2 with a Cup of Water (right)

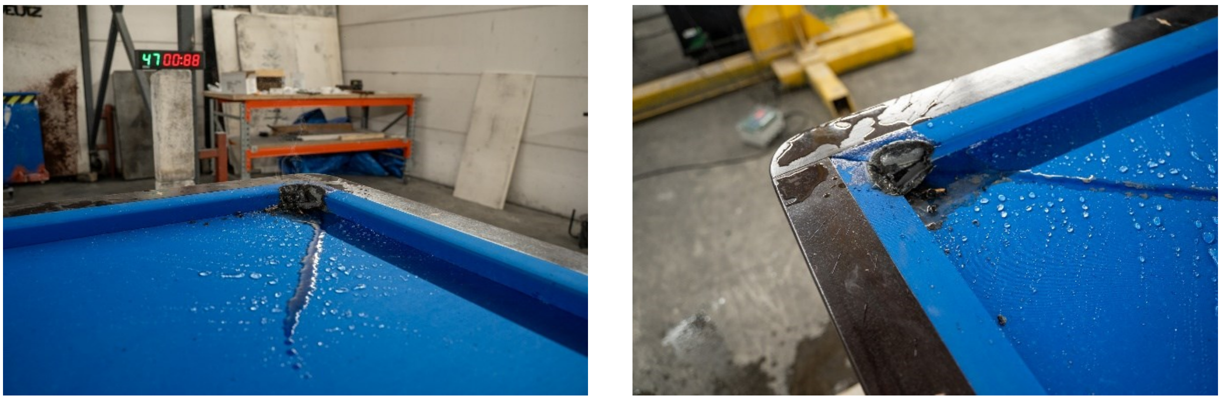


Figure 47: Charring Result of Table 2 Experiment 3

Appendix F – Heating Element and Measurement Devices

Figure 48: Heating Element in Billiard Table (left) and Radiant Flux Measurement Device (right)

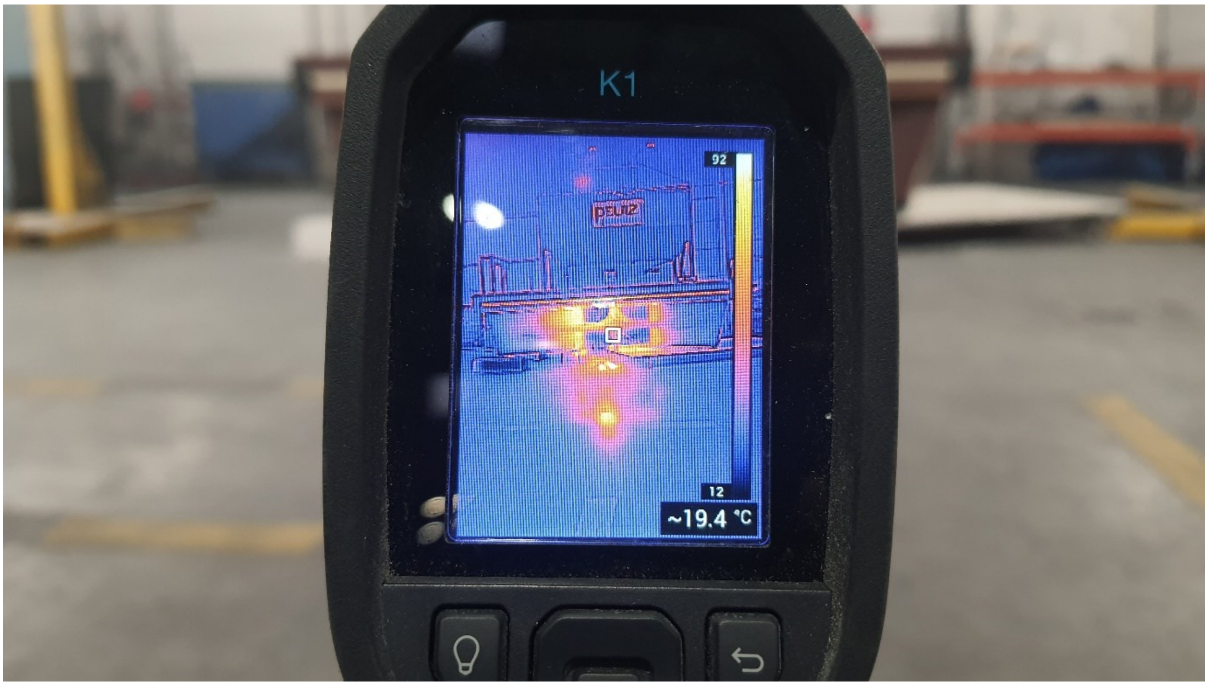


Figure 49: Thermal Camera View to Check for Smouldering of Elements

Appendix G – Soot and CO Yield Estimation

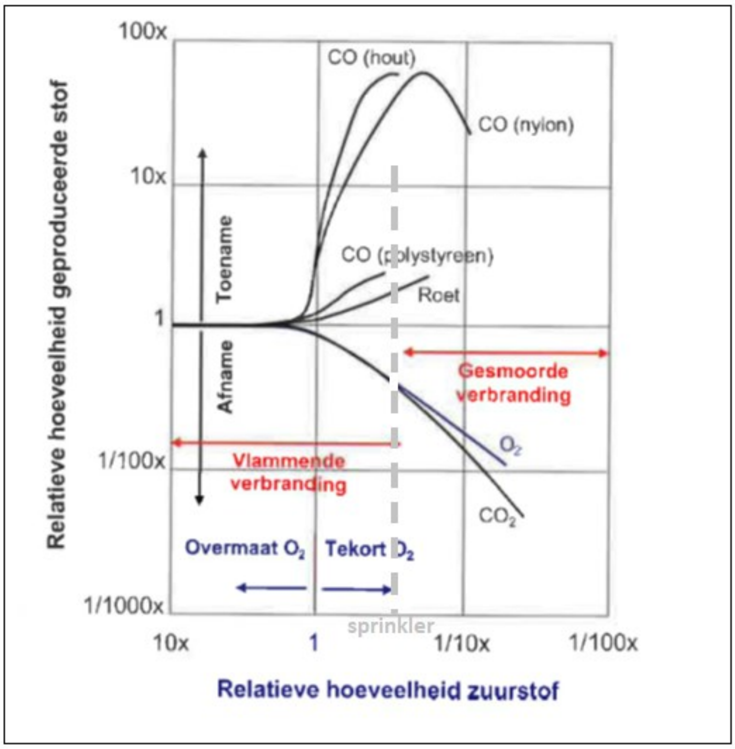


Figure 50: Soot and CO Yields for Smouldering Fire

Appendix H – Cellulose Chemistry CFAST

Table 13: CFAST Chemistry Cellulose Excel Table

	Atoms		Molar Mass		M_f			
N_C =	4		12.0107		48.0428			
N_H =	6		1.00794		6.04764			
N_O =	3		15.9994		47.9982			
N_Cl =	0		35.453		0			
N_N =	0		14.0067		0			
				M_f =	102.08864			
y_soot =	0.02643678		y_soot/y_CO2=	0.01640923				
y_HCN =	0							
y_HCl =	0							
y_CO =	0.01043986		y_CO/y_CO2=	0.00647999				
y_CO2 =	1.6110917							
Nu_soot =	0.22470756							
Nu_HCN =	0							
Nu_HCl =	0							
Nu_CO =	0.03805025							
Nu_H2O =	3							
Nu_CO2 =	3.7372422							
Nu_O2 =	3.75626732							
			H/C =	0.12588026	O/C	0.99907166		
y_soot =	0.02643678	mass fraction of the fuel wich is converted into smoke parts						
Km =	8700	CFAST 6: 3817		CFAST 7:	8700	(default)		
R =	100	rookpotentieel (mass optical density) m-1.m3/kg, this is the standard value for cellulose fires.						
If the R and Km change you get different values for the concentration.								

Appendix I – Baseline Visibility Profile

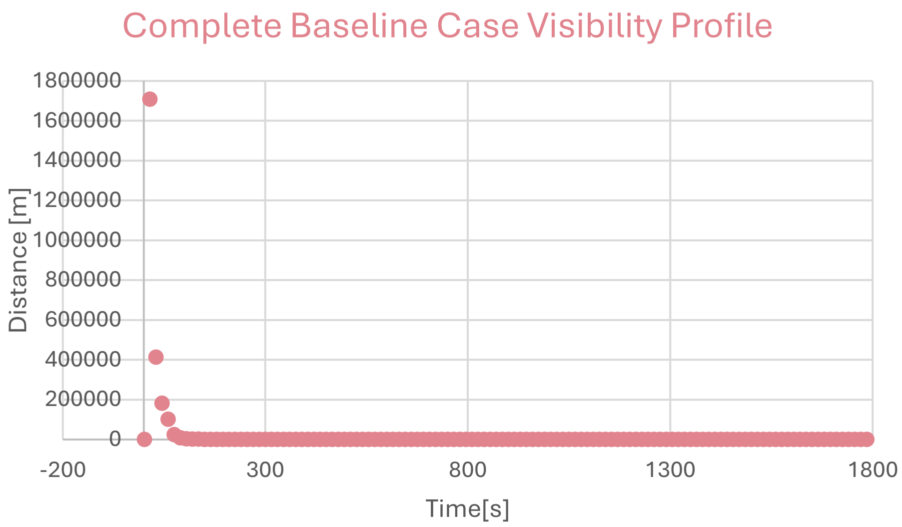


Figure 51: Complete Baseline Case Visibility Profile

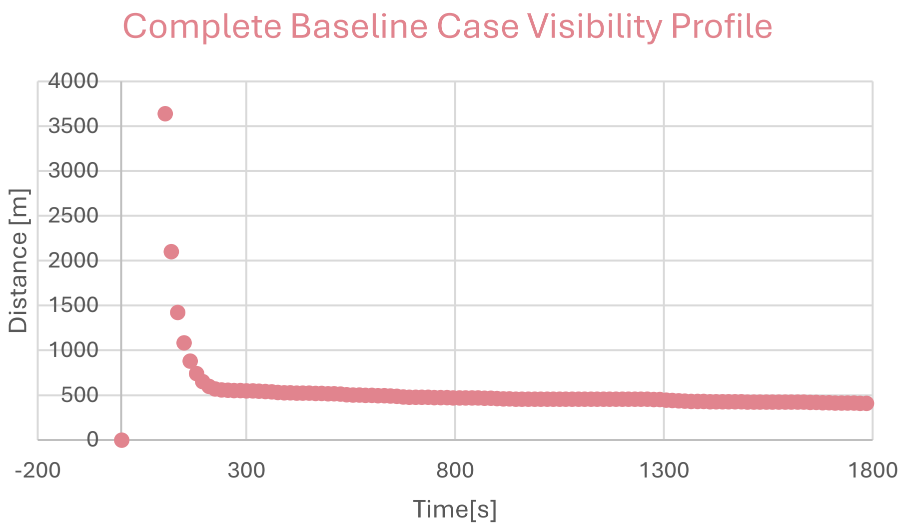


Figure 52: Baseline Case Visibility Profile with a Visibility Range in Distance of 0 to 4000 m

Appendix J – Radiation Flux Graphs

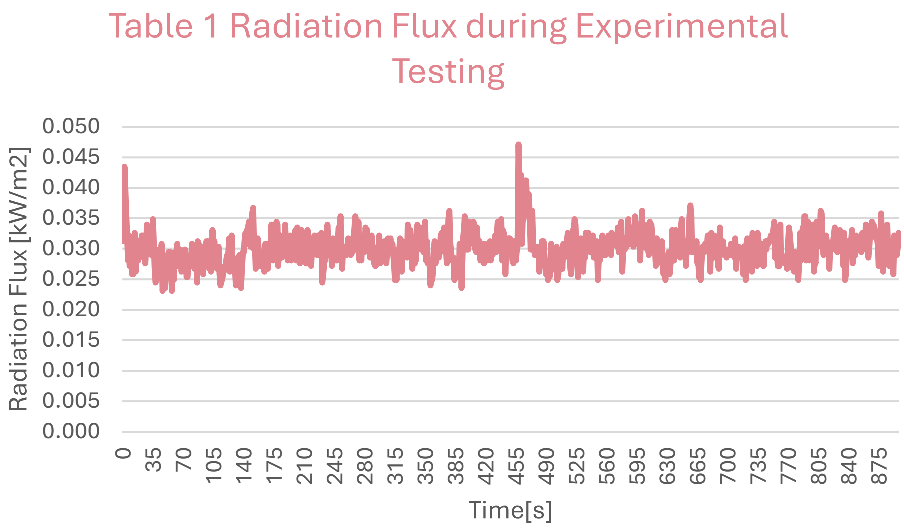


Figure 53: Table 1 Radiation Flux during Experiment Testing

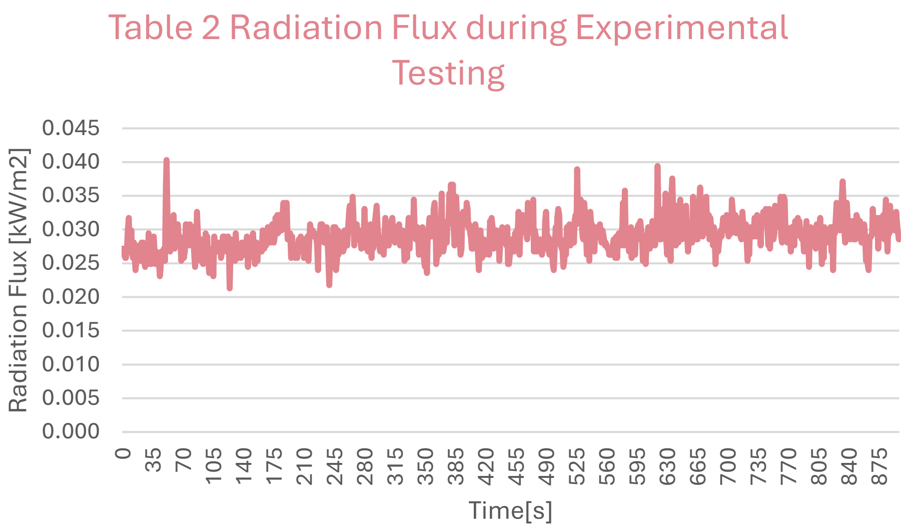


Figure 54: Table 2 Radiation Flux during Experiment Testing

From the graphs it can be concluded that the maximum radiation flux is 0.047 kW/m^2 and the minimum radiation flux is 0.021 kW/m^2. These values stay below the 1.0 kW/m^2 threshold, allowing for a great safety margin.

As a result, the radiation flux does not pose any risks to the people walking by the smoldering table as the measured values are well below the allowed maximum amount.

Appendix K – CO Measurement

Table 14: CO Meter Maximum Measured Value

Start Time	End Time	Duration(s)	Sensor Name	Event Type	Temperature	Battery Level	Peak Reading	Event Status
May/06/2026 13:46:19	May/06/2026 13:46:29	10	CO-2000	Low alarm	20	100	26ppm	N/A

Appendix L – Wooden Crib and Starting Block Ignition Comparison with Heating Element

$E_{crib} = m * H_c$

$0.05kg * 19\ 000kJ/kg = 950\ kJ = 0.95\ MJ$

$E_{blokje} = m * H_c = 0.02kg * 35\ MJ/kg = 0.70MJ$

$E_{tot} = 0.95MJ + 0.70MJ = 1.65\ MJ$

$t = E/P$

At 100W

$t = 1.65MJ/100W = 16\ 500\ s = 4.58h$

The wooden crib and starting block releases the 1.65 MJ over minutes as an ignition source

The heating element is a long duration, low-intensity source. If there’s enough time (1-3 hours at 100W) it can produce the same amount of energy

Conclusion: The crib’s total energy can match the 100W heaters energy, but the hazard mechanism differs

Appendix M – CFAST Input Overview

CFAST

Release Version : CFAST 7.7.5

Revision : CFAST-7.7.5-0-g6feca9299-release

Revision Date : Sun May 4 19:27:47 2025 -0400

Compilation Date : Sun 05/04/2025 09:07 PM

Data file: C:\Users\20210752\Desktop\VRZHZ-Fire Loads in Escape Routes-Mastersproject\CFAST Simulaions\1 Base Scenario Simulations\2 Without SHEV.in

Title: CFAST Simulation Tc atrium alleen afvoer

OVERVIEW

Compartments	Doors, ...	Ceil. Vents, ...	MV Connects
15	23	0	0

Simulation Time (s)	Output Interval (s)	Smokeview Interval (s)	Spreadsheet Interval (s)
1800.00	60.00	15.00	15.00

AMBIENT CONDITIONS

Interior Temperature (C)	Interior Pressure (Pa)	Exterior Temperature (C)	Exterior Pressure (Pa)

----

20. 101325. 20. 101325.

THERMAL PROPERTIES

Name	Conductivity (kW/(m □C))	Specific Heat (kJ/(m □C))	Density (kg/m^3)	Thickness (m)	Emissivity
COMBRICK	0.720	835.	1.920E+03	7.600E-02	0.900
CONCRETE	1.75	1.000E+03	2.200E+03	0.150	0.940
GYP1/2	0.160	900.	790.	1.300E-02	0.900
KAOWOOL	0.220	1.047E+03	128.	0.116	0.970
NM 46	2.300E-02	1.200E+03	40.0	0.100	0.900
DEFAULT	0.120	900.	800.	1.200E-02	0.900

COMPARTMENTS

Compartment	Name	Width (m)	Depth (m)	Height (m)	Floor Height (m)	Ceiling Height (m)	Shaft	Hall	Wall Leakage (m^2)	Floor Leakage (m^2)
1	Atrium_0	20.23	9.27	10.79	0.00	10.79	*		0.22	3.19E-02
2	Serre_0	11.80	4.50	2.65	0.00	2.65	*		3.02E-02	9.03E-03
3	VR_0 rechts	26.80	2.25	2.45	0.00	2.45	*		4.98E-02	1.03E-02

4	VR_0 links	12.40	3.00	2.32	0.00	2.32	*	2.50E-02	6.32E-03
5	VR_0 links ho	5.76	6.15	5.00	0.00	5.00	*	4.17E-02	6.02E-03
6	Lifthal_0	6.64	3.87	2.45	0.00	2.45	*	1.80E-02	4.37E-03
7	Trappenhuis_0	4.70	4.80	9.60	0.00	9.60	*	0.0	0.0
8	Keuken_0	3.90	1.95	2.45	0.00	2.45	*	1.00E-02	1.29E-03
9	Restaurant_0	22.15	10.40	2.40	0.00	2.40	*	5.47E-02	3.92E-02
10	Lifthal_1	6.64	2.88	2.45	2.70	5.15	*	1.63E-02	3.25E-03
11	VR_1 onder li	10.46	2.25	2.45	2.70	5.15	*	2.18E-02	4.00E-03
12	VR_1 rechts	18.70	2.25	2.45	2.70	5.15	*	3.59E-02	7.15E-03
13	Lifthal_2	6.64	2.88	2.45	5.40	7.85	*	1.63E-02	3.25E-03
14	VR_2 onder li	10.46	2.25	2.45	5.40	7.85	*	1.06E-02	4.00E-03
15	VR_2 rechts	18.70	2.25	2.45	5.40	7.85	*	3.59E-02	7.15E-03

COMPARTMENT MATERIALS

Compartment	Name	Surface	Layer	Conductivity	Specific Heat	Density	Thickness	Emissivity	Material
				(kW/(m C))	(kJ/(m C))	(kg/m^3)	(m)		
1	Atrium_0	Ceiling	1	2.300E-02	1.200E+03	40.0	0.150	0.900	NM 46
		Floor	1	1.75	1.000E+03	2.200E+03	0.150	0.940	CONCRETE

Walls 1 0.720 835. 1.920E+03 0.100
0.900 COMBRICK

2 Serre_0 Ceiling 1 2.300E-02 1.200E+03 40.0 0.110
0.900 NM 46

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

Walls 1 2.300E-02 1.200E+03 40.0 0.110
0.900 NM 46

3 VR_0 rechts Ceiling 1 0.220 1.047E+03 128. 2.000E-
02 0.970 KAOWOOL

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

4 VR_0 links Ceiling 1 0.160 900. 790. 1.200E-02
0.900 GYP1/2

Floor 1 1.75 1.000E+03 2.200E+03 0.315
0.940 CONCRETE

5 VR_0 links ho Ceiling 1 1.75 1.000E+03 2.200E+03 0.200
0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.315
0.940 CONCRETE

6 Lifthal_0 Ceiling 1 1.75 1.000E+03 2.200E+03 0.200
0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

7 Trappenhuis_0 Ceiling 1 2.300E-02 1.200E+03 40.0
0.100 0.900 NM 46

Floor 1 1.75 1.000E+03 2.200E+03 0.315
0.940 CONCRETE

Walls 1 2.300E-02 1.200E+03 40.0 0.100
0.900 NM 46

8 Keuken_0 Ceiling 1 0.160 900. 790. 2.000E-02
0.900 GYP1/2

Floor 1 1.75 1.000E+03 2.200E+03 0.315
0.940 CONCRETE

Walls 1 0.220 1.047E+03 128. 7.000E-02
0.970 KAOWOOL

9 Restaurant_0 Ceiling 1 0.220 1.047E+03 128. 2.000E-
02 0.970 KAOWOOL

Floor 1 1.75 1.000E+03 2.200E+03 0.315
0.940 CONCRETE

10 Lifthal_1 Ceiling 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

11 VR_1 onder li Ceiling 1 1.75 1.000E+03 2.200E+03 0.200
0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

12 VR_1 rechts Ceiling 1 1.75 1.000E+03 2.200E+03
0.150 0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

13 Lifthal_2 Ceiling 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

14 VR_2 onder li Ceiling 1 1.75 1.000E+03 2.200E+03
0.150 0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

15 VR_2 rechts Ceiling 1 1.75 1.000E+03 2.200E+03
0.150 0.940 CONCRETE

Floor 1 1.75 1.000E+03 2.200E+03 0.150
0.940 CONCRETE

VENT CONNECTIONS

Wall Vents (Doors, Windows, ...)

From To Vent Width Sill Soffit Open/Close Trigger
Initial Initial Final Final

Compartment Compartment Number Height Height Type Value
Target Time Fraction Time Fraction

(m) (m) (m) (m) (C/W/m^2) (s)
(s)

Atrium_0 Serre_0 1 7.40 0.00 2.10 Time 0.00
0.00 1800.00 0.00

Atrium_0 VR_0 links 2 1.90 0.00 2.10 RAMP # 1

VR_0 links Outside 3 1.30 0.00 2.10 RAMP # 2

VR_0 links VR_0 links hoo 4 3.00 0.00 2.32 Time
0.00 1.00

VR_0 links hoo Outside 5 6.00 2.10 3.50 RAMP # 3

Atrium_0 Restaurant_0 6 4.20 0.00 2.30 RAMP # 4

Atrium_0 VR_0 rechts 7 2.25 0.00 2.45 Time
0.00 1.00

Atrium_0 Keuken_0 8 1.27 1.50 2.10 Time
0.00 0.00 1800.00 0.00

VR_0 rechts Keuken_0 9 1.32 0.00 2.10 Time
0.00 0.00 1800.00 0.00

VR_0 rechts Outside 10 2.00 0.00 2.10 RAMP # 5

Atrium_0 Lifthal_0 11 1.90 0.00 2.10 RAMP # 6

Lifthal_0 Trappenhuis_0 12 3.80 0.00 2.45 Time
0.00 1.00

VR_0 links hoo Lifthal_0 13 1.90 0.00 2.10 RAMP # 7

Restaurant_0 Outside 14 2.00 0.00 2.10 Time
180.00 0.00 240.00 0.00

Atrium_0 Lifthal_1 15 1.90 2.70 4.80 RAMP # 8

Atrium_0 VR_1 onder lin 16 1.90 2.70 4.80 RAMP # 9

Atrium_0 VR_1 rechts 17 1.90 2.70 4.80 RAMP # 10

Trappenhuis_0 Lifthal_1 18 3.80 2.70 5.15 Time
0.00 1.00

VR_0 links hoo Lifthal_1 19 1.90 2.70 4.80 RAMP # 11

Atrium_0 Lifthal_2 20 1.90 5.40 7.50 RAMP # 12

Atrium_0 VR_2 onder lin 21 1.90 5.40 7.50 RAMP # 13

Atrium_0 VR_2 rechts 22 1.90 5.40 7.50 RAMP # 14

Trappenhuis_0 Lifthal_2 23 3.80 5.40 7.85 Time
0.00 1.00

There are no vertical natural flow connections

There are no mechanical flow connections

VENT RAMPS

Type	From Compartment	To Compartment	Vent Number		(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)
H	Atrium_0	VR_0 links	1	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	VR_0 links	Outside	2	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	VR_0 links hoo	Outside	3	Time	0	180	1800							
				Fraction	0.00	0.00	0.00							
H	Atrium_0	Restaurant_0	4	Time	0	120	180							
				Fraction	1.00	1.00	0.00							
H	VR_0 rechts	Outside	5	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Atrium_0	Lifthal_0	6	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	VR_0 links hoo	Lifthal_0	7	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Atrium_0	Lifthal_1	8	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Atrium_0	VR_1 onder lin	9	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					
H	Atrium_0	VR_1 rechts	10	Time	0	120	121	180	181					
				Fraction	0.00	0.00	1.00	1.00	0.00					

H VR_0 links hoo Lifthal_1 11 Time 0 120 121 180 181

Fraction 0.00 0.00 1.00 1.00 0.00

H Atrium_0 Lifthal_2 12 Time 0 120 121 180 181

Fraction 0.00 0.00 1.00 1.00 0.00

H Atrium_0 VR_2 onder lin 13 Time 0 120 121 180 181

Fraction 0.00 0.00 1.00 1.00 0.00

H Atrium_0 VR_2 rechts 14 Time 0 120 121 180 181

Fraction 0.00 0.00 1.00 1.00 0.00

FIRES

Name: Real_Fire Referenced as object # 1 Normal fire

Compartment	Fire Type	Time to Flaming	Position (x,y,z)			Relative Humidity	Lower O2 Limit	Radiative Fraction
Atrium_0	Constrained	0.0	11.07	5.08	0.00	50.0	15.00	0.00

Chemical formula of the fuel

Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
4.000	6.000	3.000	0.000	0.000

Time (s)	Mdot (kg/s)	Hcomb (J/kg)	Qdot (W)	Zoffset (m)	Soot (kg/kg)	CO (kg/kg)	HCN (kg/kg)	HCl (kg/kg)	TS (kg/kg)
0.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
60.	4.42E-06	1.90E+07	84.	0.0	5.20E-02	0.10	0.0	0.0	0.0
120.	2.05E-04	1.90E+07	3.90E+03	0.0	5.20E-02	0.10	0.0	0.0	0.0

180.	1.89E-04	1.90E+07	3.60E+03	0.0	5.20E-02	0.10	0.0	0.0	0.0
240.	8.75E-06	1.90E+07	1.66E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
300.	5.42E-06	1.90E+07	1.03E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
360.	1.75E-05	1.90E+07	3.32E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
420.	4.17E-06	1.90E+07	79.	0.0	5.20E-02	0.10	0.0	0.0	0.0
480.	6.58E-06	1.90E+07	1.25E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
540.	1.65E-05	1.90E+07	3.14E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
600.	3.58E-06	1.90E+07	68.	0.0	5.20E-02	0.10	0.0	0.0	0.0
660.	1.93E-05	1.90E+07	3.66E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
720.	2.67E-06	1.90E+07	51.	0.0	5.20E-02	0.10	0.0	0.0	0.0
780.	6.75E-06	1.90E+07	1.28E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
840.	2.08E-06	1.90E+07	40.	0.0	5.20E-02	0.10	0.0	0.0	0.0
900.	1.37E-05	1.90E+07	2.60E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
960.	1.33E-06	1.90E+07	25.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1020.	1.00E-06	1.90E+07	19.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1080.	2.00E-06	1.90E+07	38.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1140.	6.67E-07	1.90E+07	13.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1200.	1.00E-06	1.90E+07	19.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1260.	2.67E-06	1.90E+07	51.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1320.	2.67E-05	1.90E+07	5.07E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
1380.	2.67E-06	1.90E+07	51.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1440.	3.33E-06	1.90E+07	63.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1500.	4.00E-06	1.90E+07	76.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1560.	1.33E-06	1.90E+07	25.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1620.	2.33E-06	1.90E+07	44.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1680.	1.17E-05	1.90E+07	2.22E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
1740.	4.33E-06	1.90E+07	82.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1800.	7.00E-06	1.90E+07	1.33E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
1860.	6.53E-05	1.90E+07	1.24E+03	0.0	5.20E-02	0.10	0.0	0.0	0.0
1920.	2.67E-06	1.90E+07	51.	0.0	5.20E-02	0.10	0.0	0.0	0.0
1980.	3.33E-06	1.90E+07	63.	0.0	5.20E-02	0.10	0.0	0.0	0.0
2040.	1.13E-05	1.90E+07	2.15E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0

2100.	6.67E-06	1.90E+07	1.27E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2160.	6.67E-06	1.90E+07	1.27E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2220.	5.67E-06	1.90E+07	1.08E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2280.	8.00E-06	1.90E+07	1.52E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2340.	1.57E-05	1.90E+07	2.98E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2400.	2.80E-05	1.90E+07	5.32E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2460.	3.77E-05	1.90E+07	7.16E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2520.	5.07E-05	1.90E+07	9.63E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2580.	8.33E-06	1.90E+07	1.58E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2640.	6.00E-06	1.90E+07	1.14E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2700.	7.33E-06	1.90E+07	1.39E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2760.	8.67E-06	1.90E+07	1.65E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2820.	1.07E-05	1.90E+07	2.03E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2880.	2.07E-05	1.90E+07	3.93E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
2940.	2.10E-05	1.90E+07	3.99E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3000.	1.07E-05	1.90E+07	2.03E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3060.	8.67E-06	1.90E+07	1.65E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3120.	6.00E-06	1.90E+07	1.14E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3180.	8.33E-06	1.90E+07	1.58E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3240.	3.73E-05	1.90E+07	7.09E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3300.	3.73E-05	1.90E+07	7.09E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3360.	4.90E-05	1.90E+07	9.31E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3420.	2.50E-05	1.90E+07	4.75E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3480.	2.20E-05	1.90E+07	4.18E+02	0.0	5.20E-02	0.10	0.0	0.0	0.0
3540.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3600.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3660.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3720.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3780.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3840.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3900.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0
3960.	0.0	1.90E+07	0.0	0.0	5.20E-02	0.10	0.0	0.0	0.0

```
4020.    0.0    1.90E+07  0.0    0.0    5.20E-02  0.10    0.0    0.0    0.0
```

```
DETECTORS/ALARMS/SPRINKLERS

Target  Compartment       Type         Position (x, y, z)         Activation     Flaming
Smoldering

                                                  Obscuration   Obscuration   Obscuration
Temperature   RTI         Spray Density

                               (m)     (m)     (m)        (%/m)        (%/m)        (%/m)        (C)
(m s)^1/2     (mm/s)

-------------------------------------------------------------------------------------------------------------------------
------------------------------------

 1    Serre_0         HEAT       11.25     1.12     2.45
30.00          5.00

 2    Serre_0         HEAT       11.25     1.12     2.45
25.00          5.00

 3    Serre_0         SMOKE       11.25     1.12     2.45                    23.93          23.93

 4    Atrium_0         HEAT       11.07     3.95     9.83
30.00          5.00

 5    Atrium_0         HEAT       11.07     3.95     9.83
25.00          5.00

 6    Atrium_0         SMOKE       11.07     3.95     9.83                    23.93          23.93

 7    Keuken_0         HEAT       2.00     1.00     2.45
30.00          5.00

 8    Keuken_0         HEAT       2.00     1.00     2.45
25.00          5.00

 9    Keuken_0         SMOKE       2.00     1.00     2.45                    23.93          23.93
```

Appendix N – SmokeView Temperature Slice Outputs at 0, 5, 10, 15, and 30 minutes of the Base Scenario

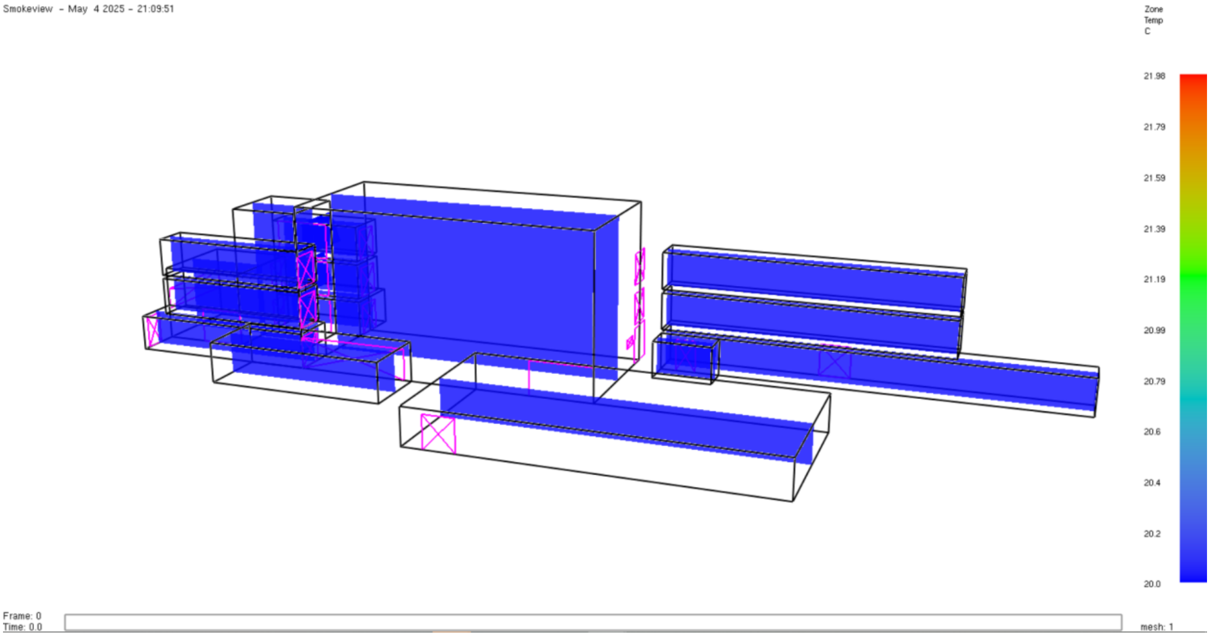


Figure 55: SmokeView Temperature Slice Output at 0 minutes

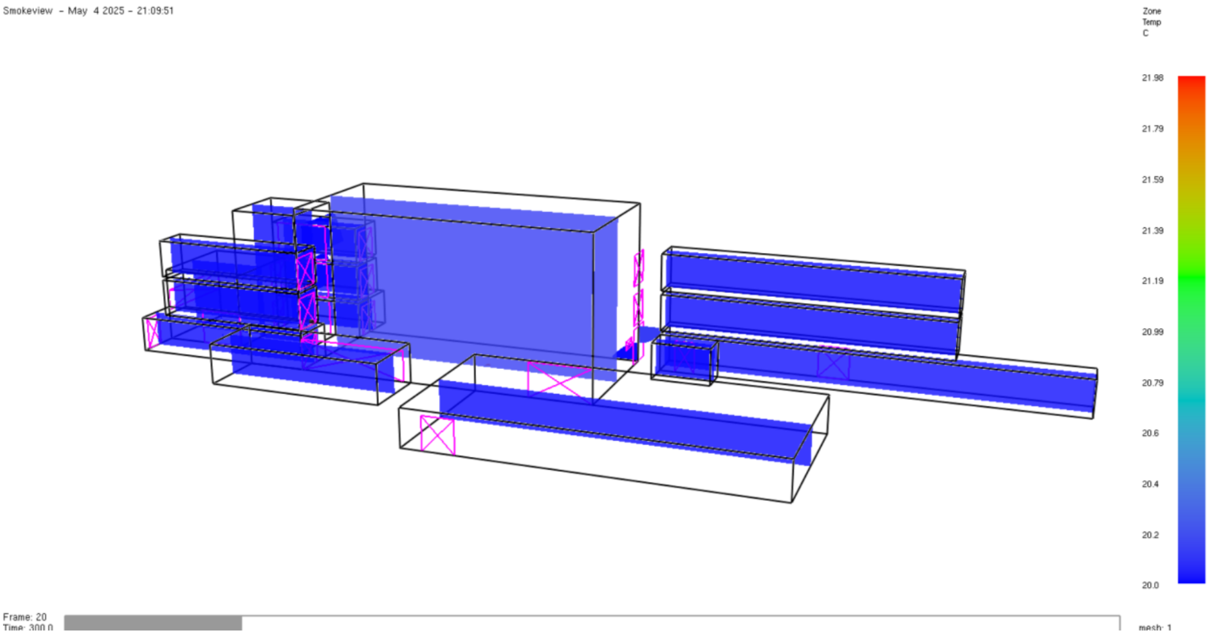


Figure 56: SmokeView Temperature Slice Output at 5 minutes

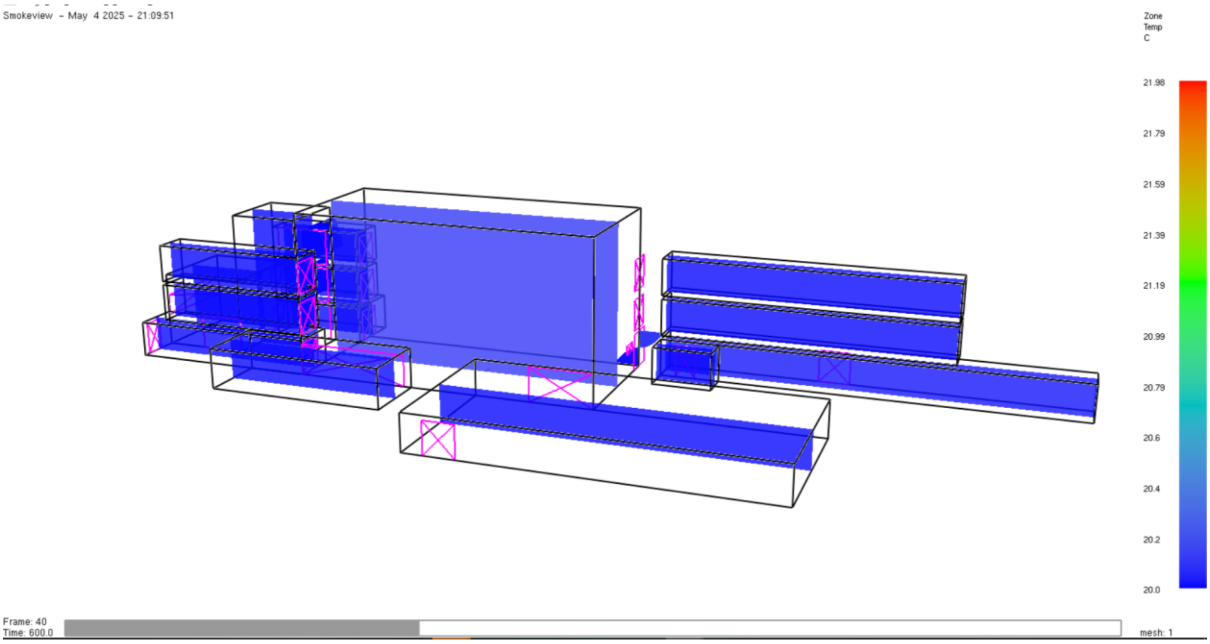


Figure 57: SmokeView Temperature Slice Output at 10 minutes

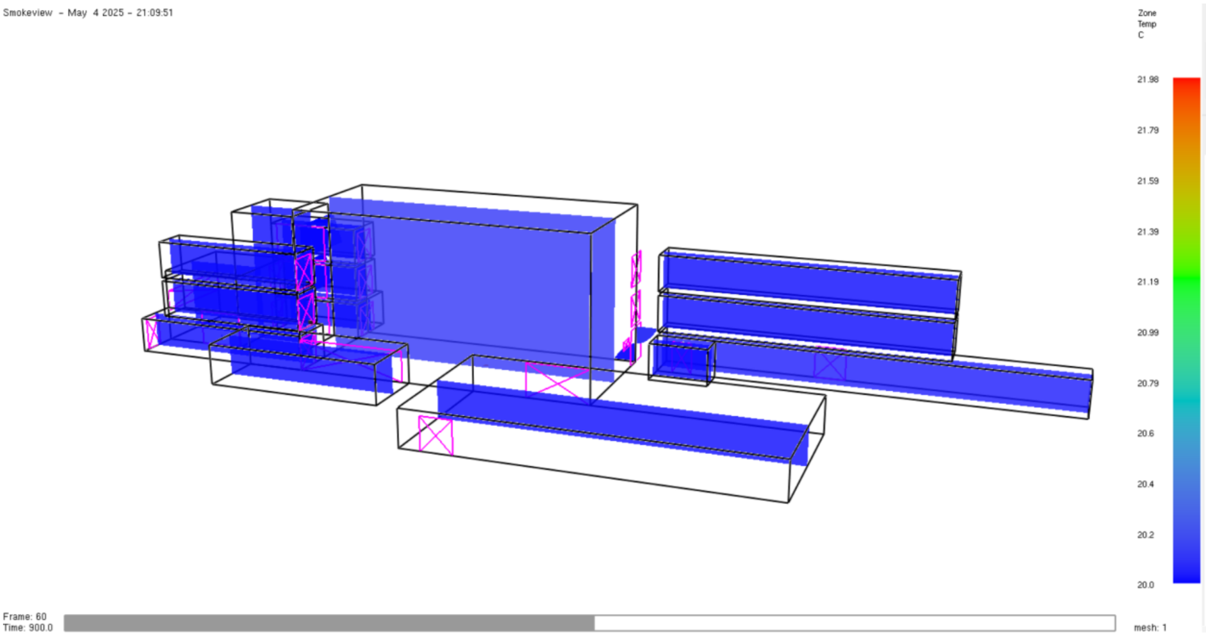


Figure 58: SmokeView Temperature Slice Output at 15 minutes

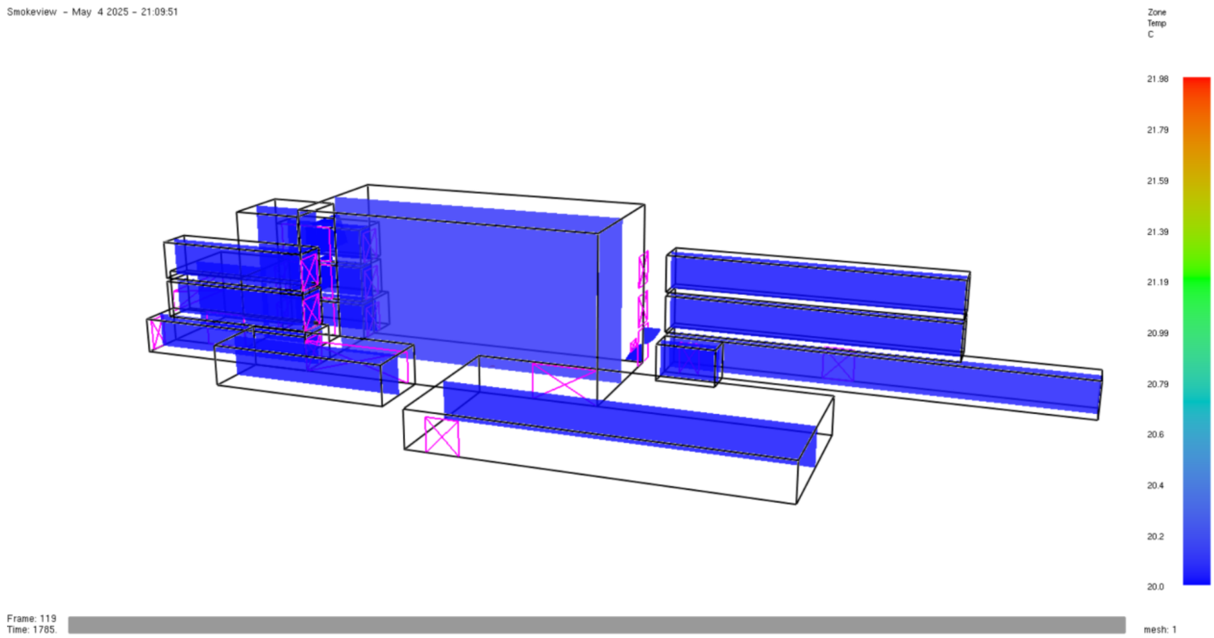


Figure 59: SmokeView Temperature Slice Output at 30 minutes

Appendix O - SmokeView Smoke Slice Outputs at 0, 5, 10, 15, and 30 minutes of the Base Scenario

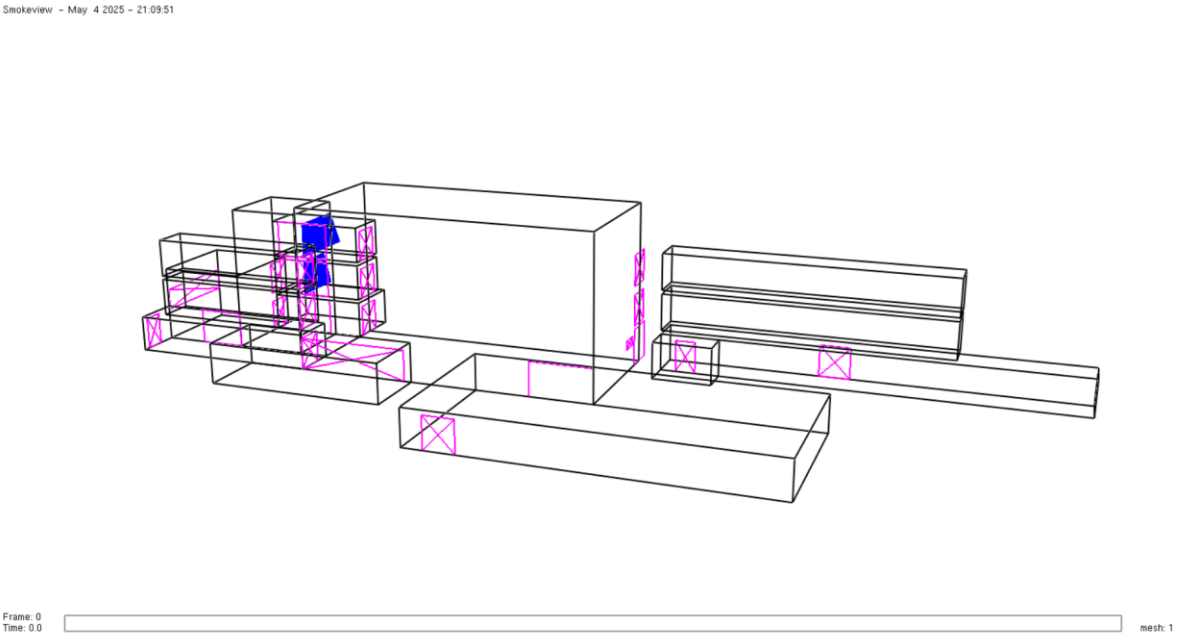


Figure 60: SmokeView Smoke Slice Output at 0 minutes

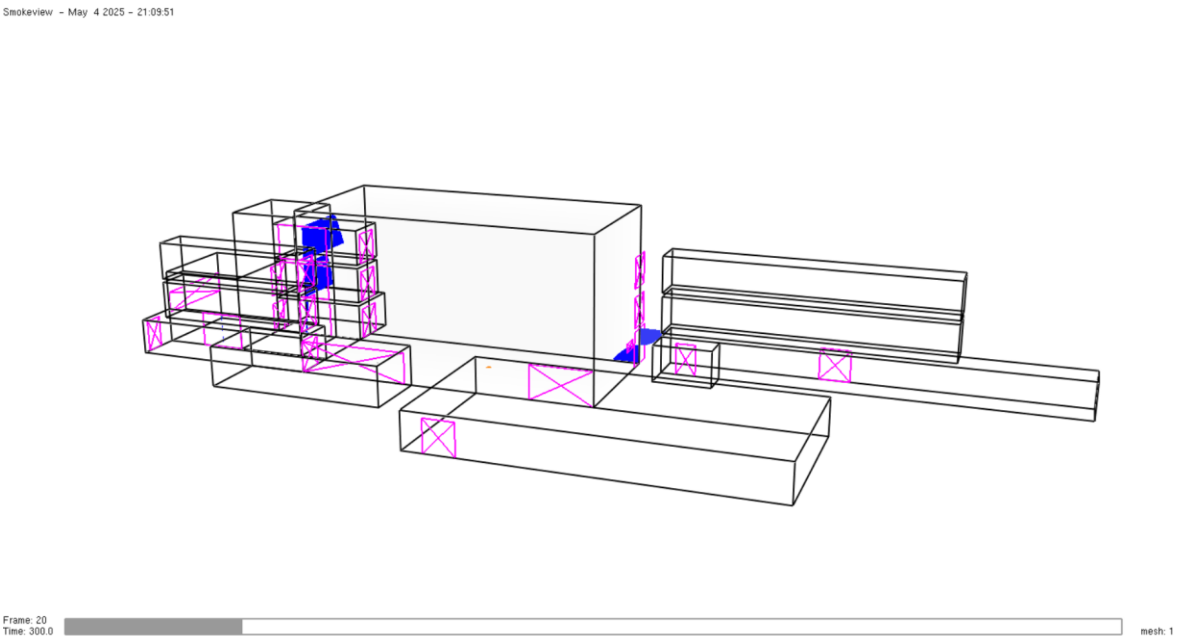


Figure 61: SmokeView Smoke Slice Output at 5 minutes

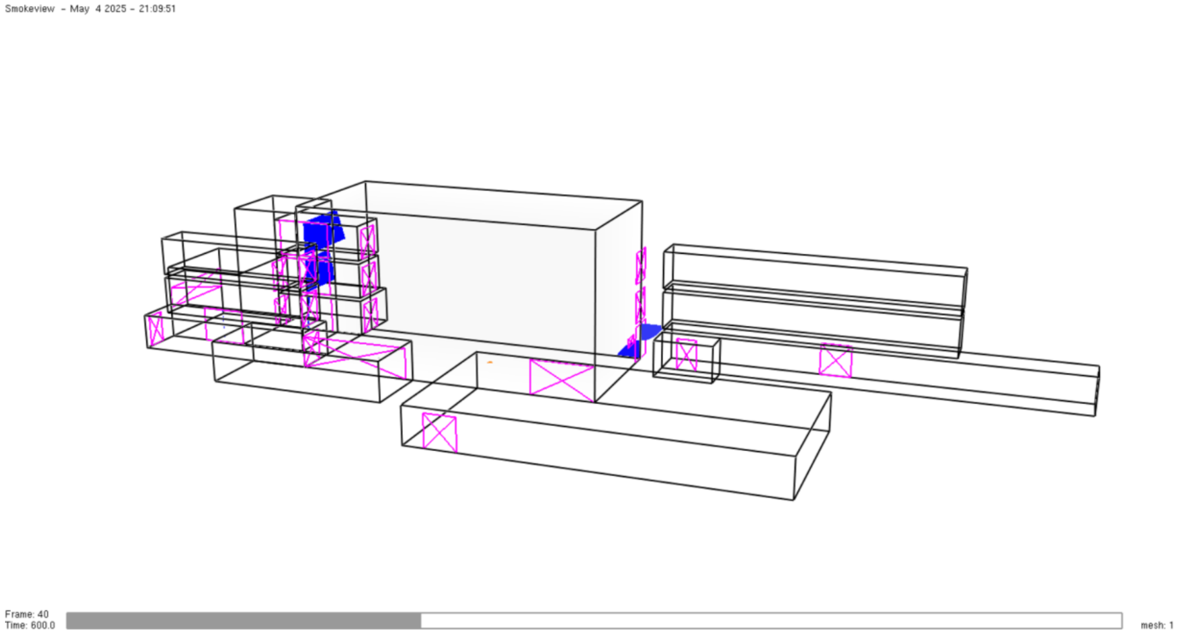


Figure 62: SmokeView Smoke Slice Output at 10 minutes

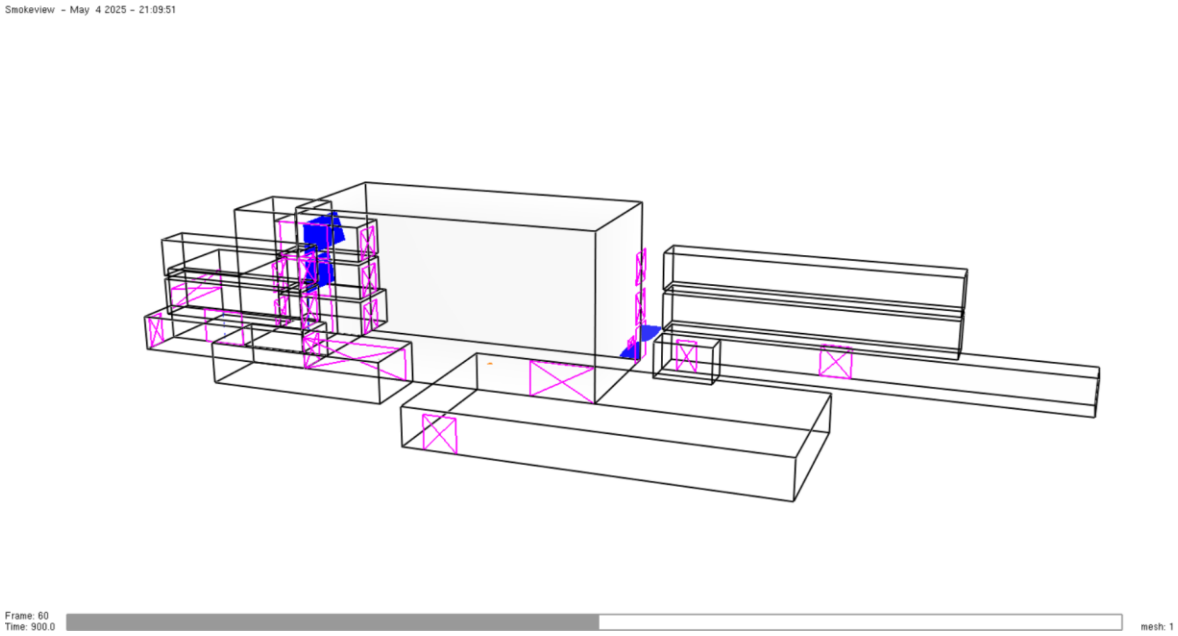


Figure 63: SmokeView Smoke Slice Output at 15 minutes

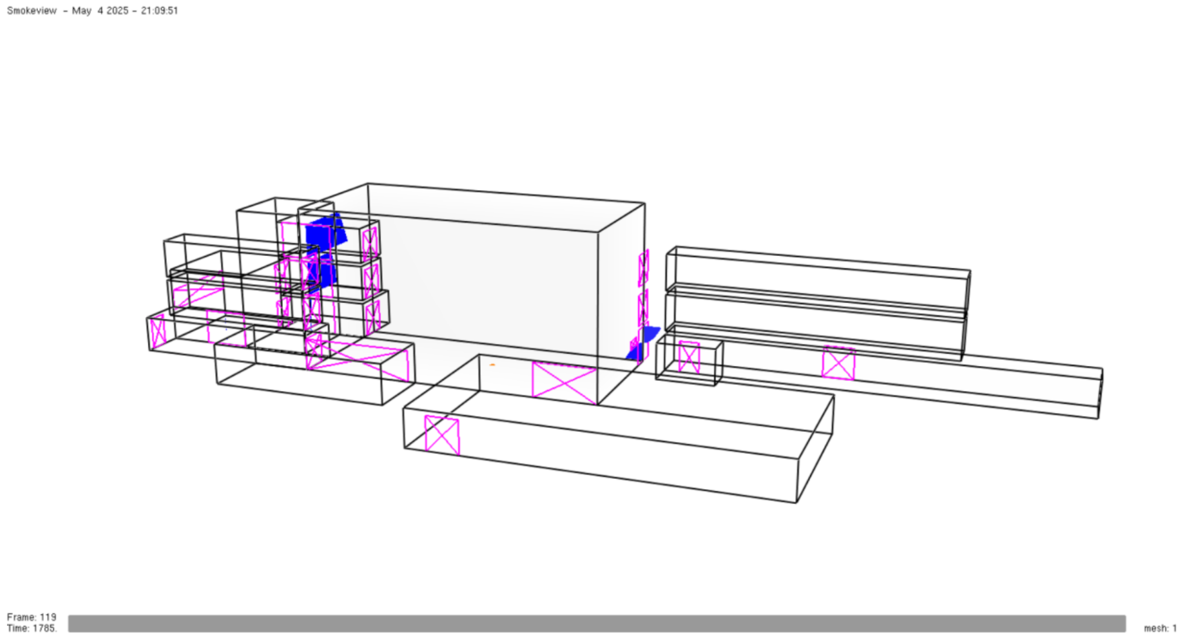


Figure 64: SmokeView Smoke Slice Output at 30 minutes

Appendix P – Pathfinder Inputs (Simulation 3.3)

Evacuating Care Workers:1

Self-Reliant Senior Citizens: 20

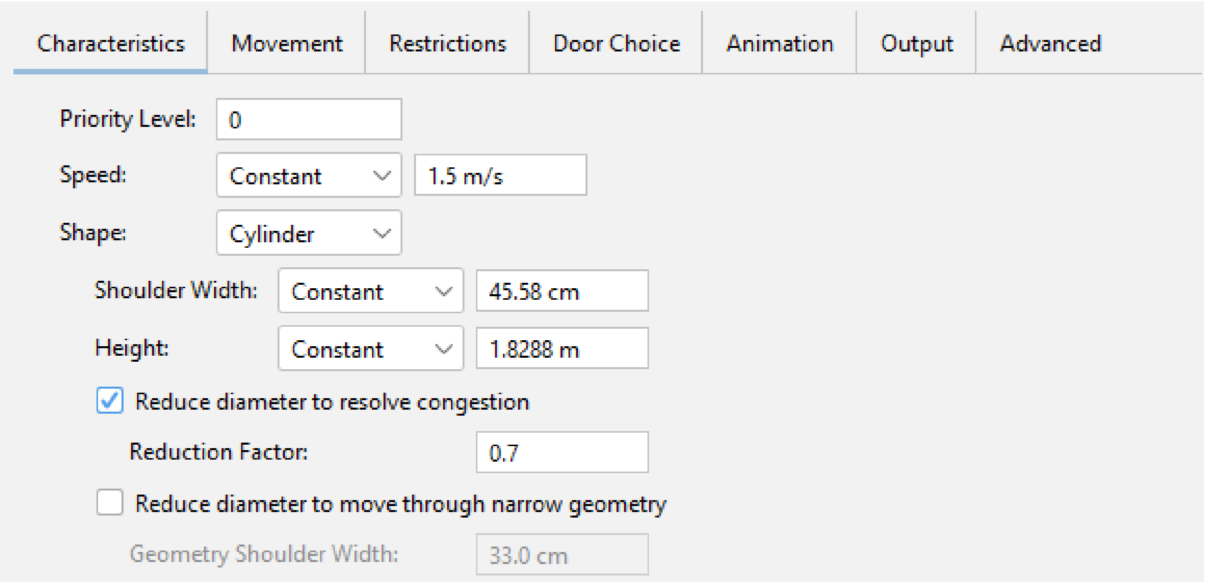
Non-Self-Reliant Senior Citizens: 20 (located in their rooms)

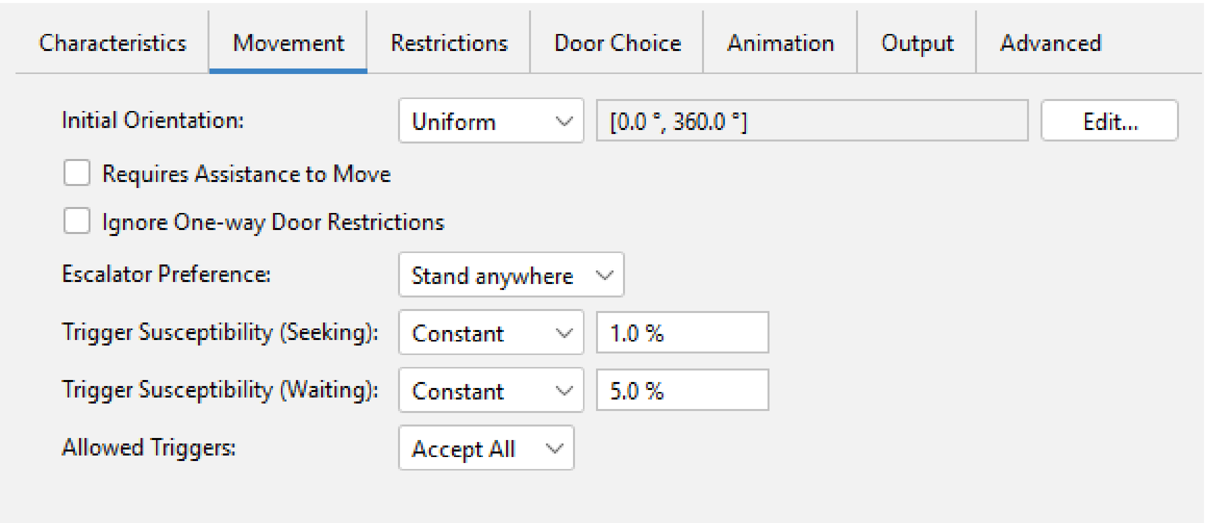
Other People (Self-Reliant): 28 (located in the surroundings of the atrium

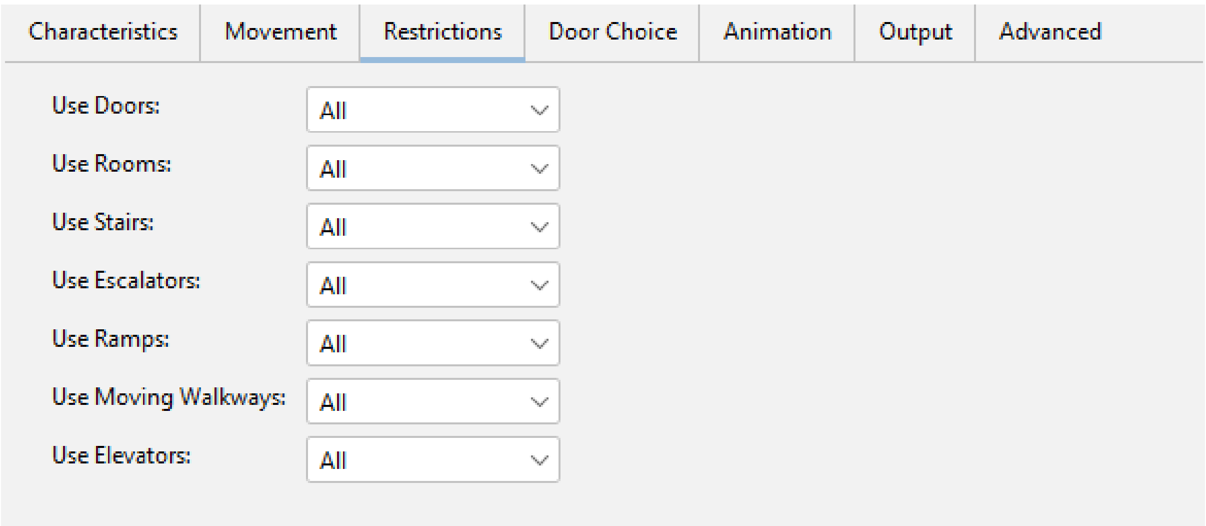
Exit Usage: Less known exits are not used (less known exits mean evacuation route to adjacent building)

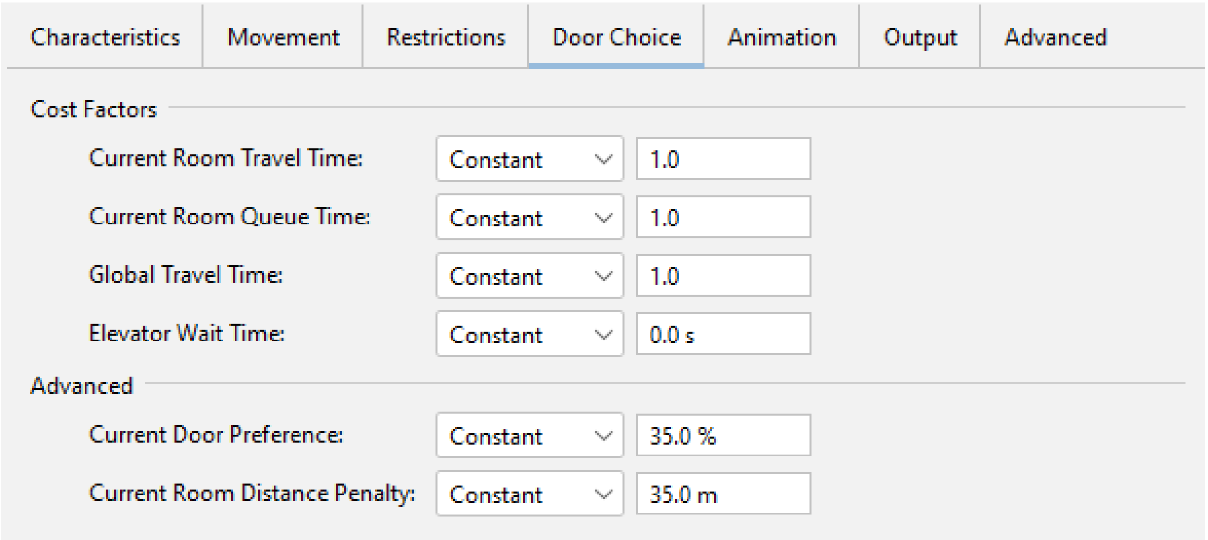
Evacuation Scenario: Full Evacuation

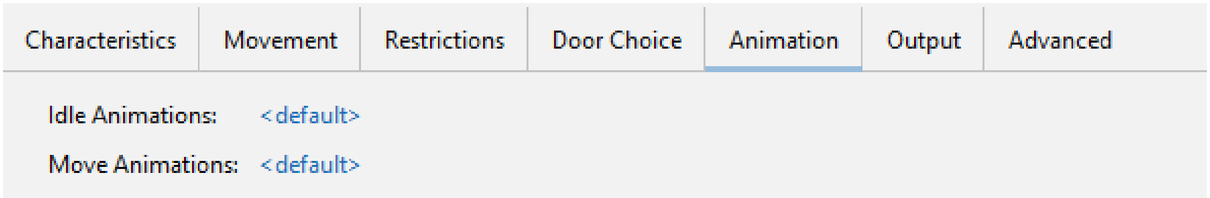
Care Worker Movement Parameters:

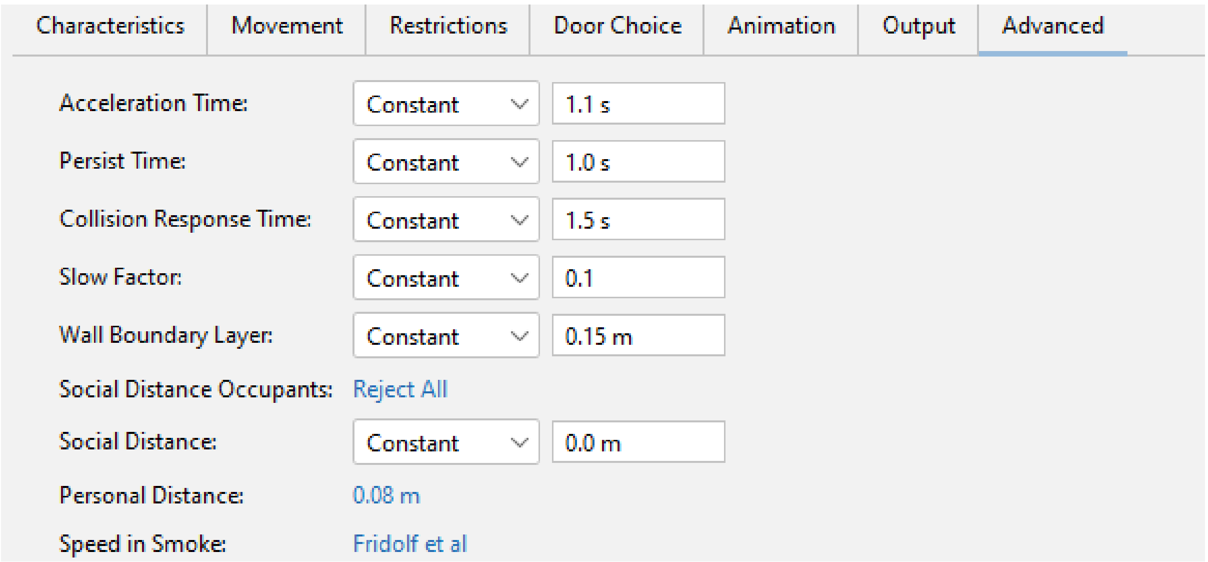




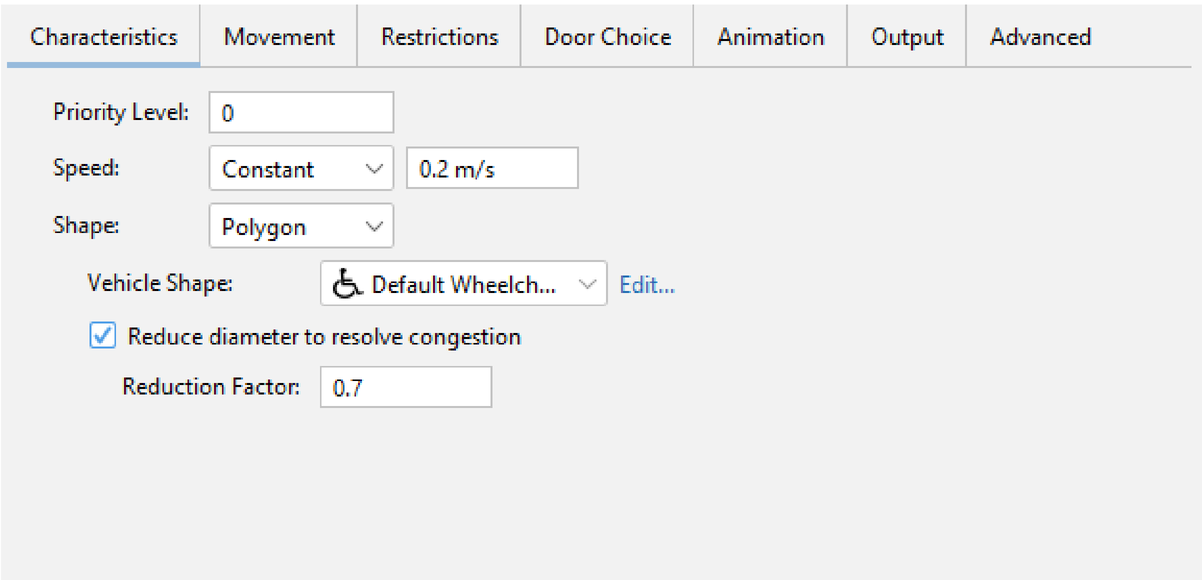

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Use Doors: All
Use Rooms: All
Use Stairs: All
Use Escalators: All
Use Ramps: All
Use Moving Walkways: All
Use Elevators: All

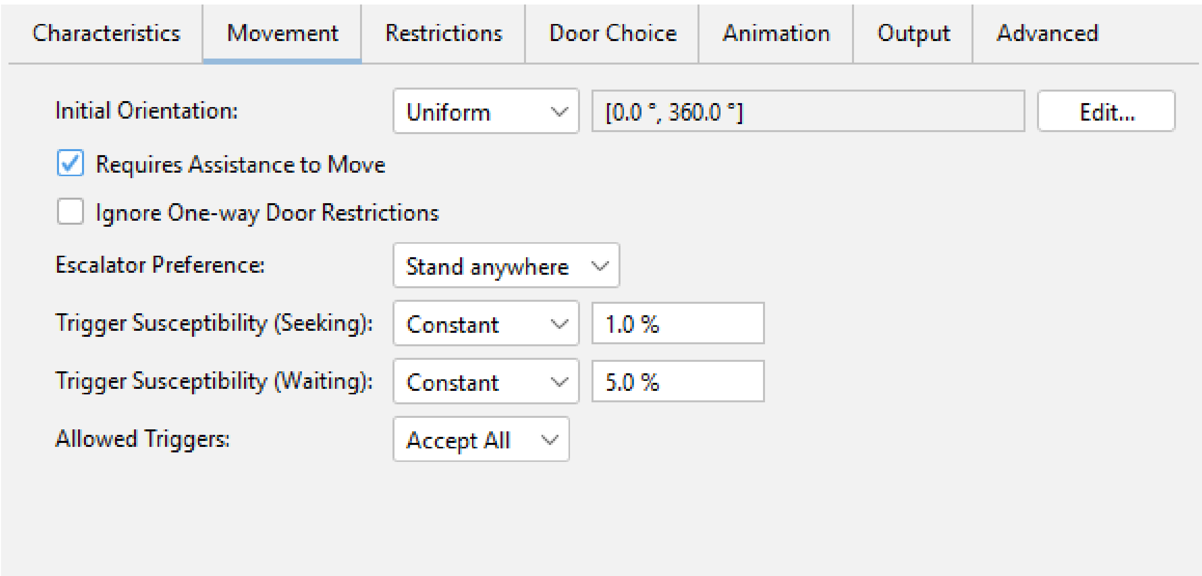

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Cost Factors
Current Room Travel Time: Constant 1.0
Current Room Queue Time: Constant 1.0
Global Travel Time: Constant 1.0
Elevator Wait Time: Constant 0.0 s
Advanced
Current Door Preference: Constant 35.0 %
Current Room Distance Penalty: Constant 35.0 m

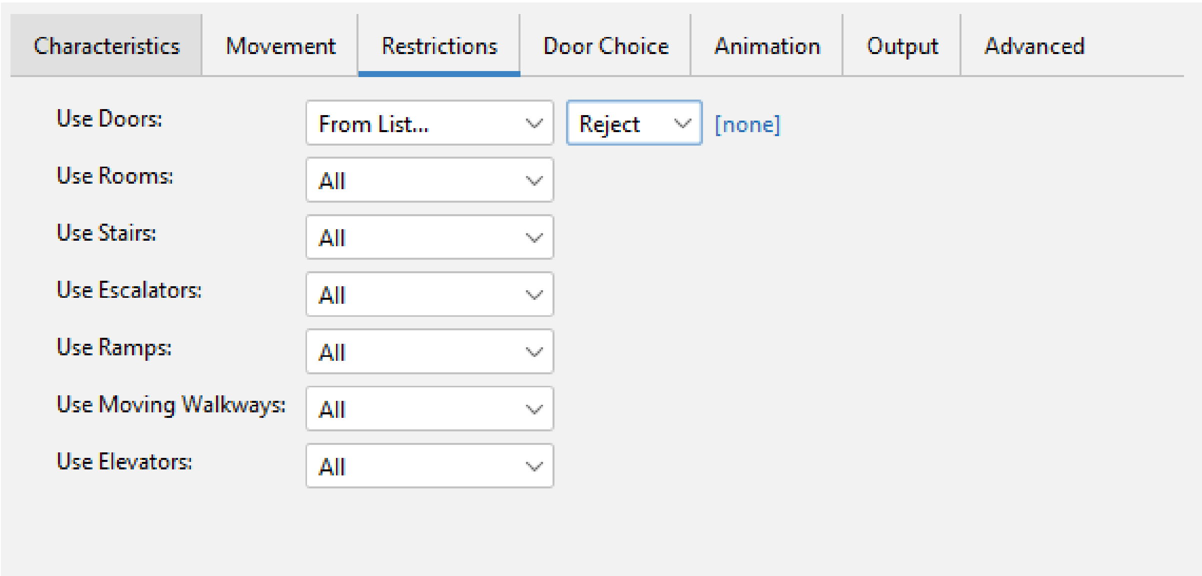

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Idle Animations: <default>
Move Animations: <default>

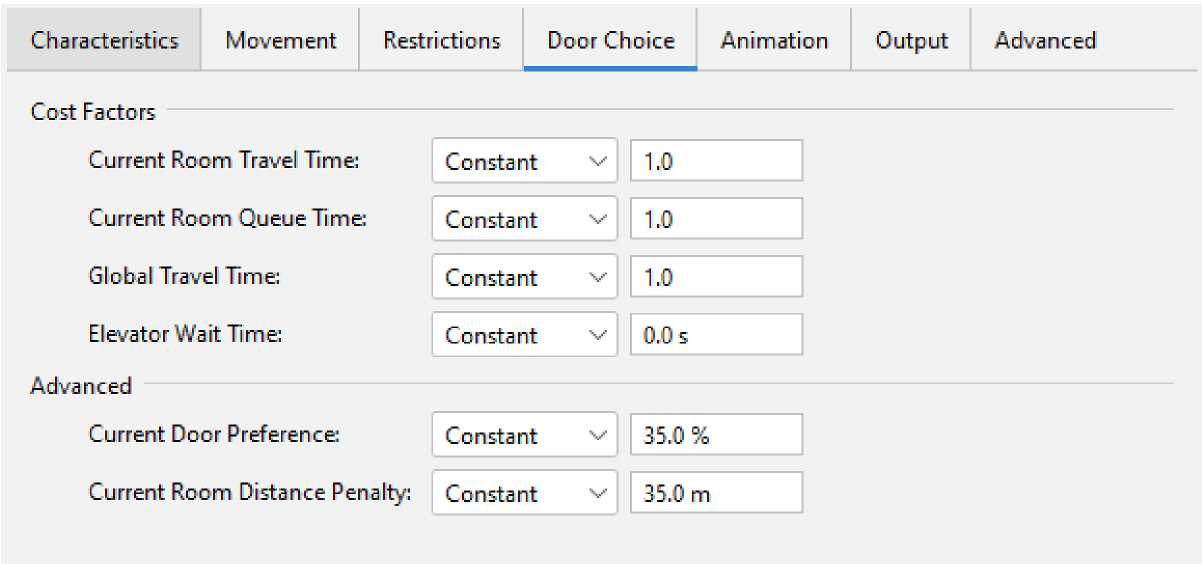


Patient Movement Parameters:

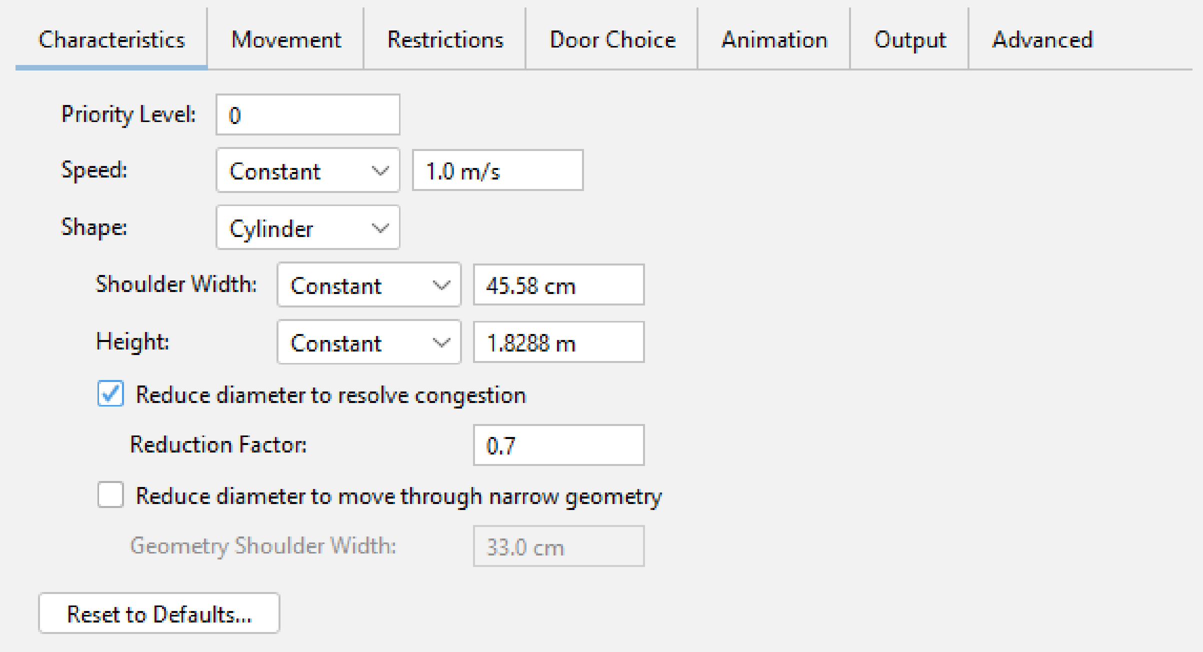


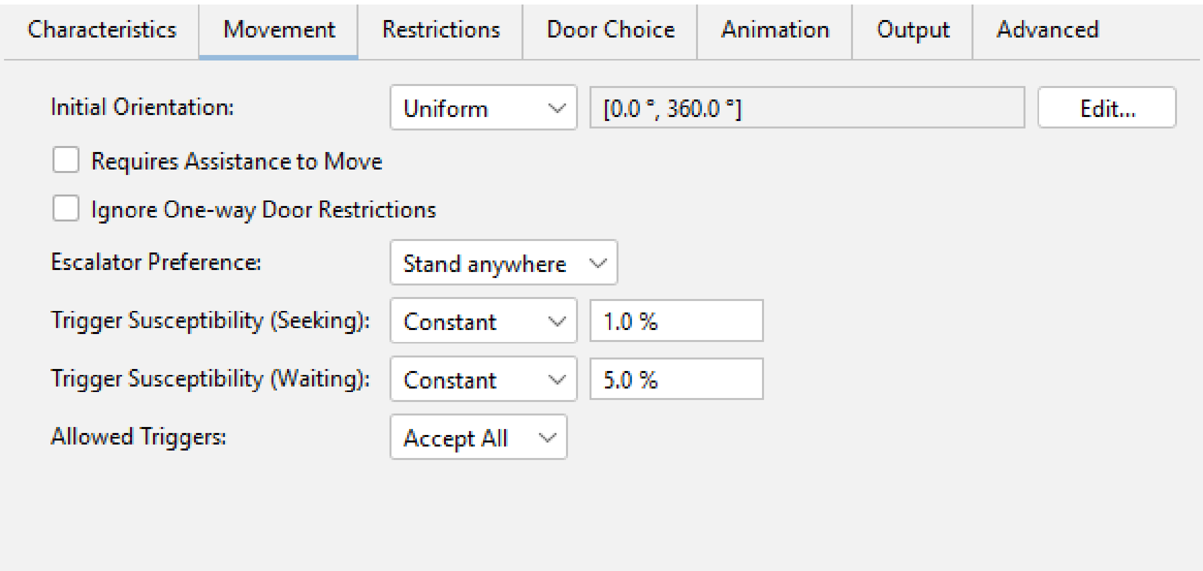

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Initial Orientation:
Uniform
[0.0 °, 360.0 °]
Edit...
Requires Assistance to Move
Ignore One-way Door Restrictions
Escalator Preference:
Stand anywhere
Trigger Susceptibility (Seeking):
Constant
1.0 %
Trigger Susceptibility (Waiting):
Constant
5.0 %
Allowed Triggers:
Accept All

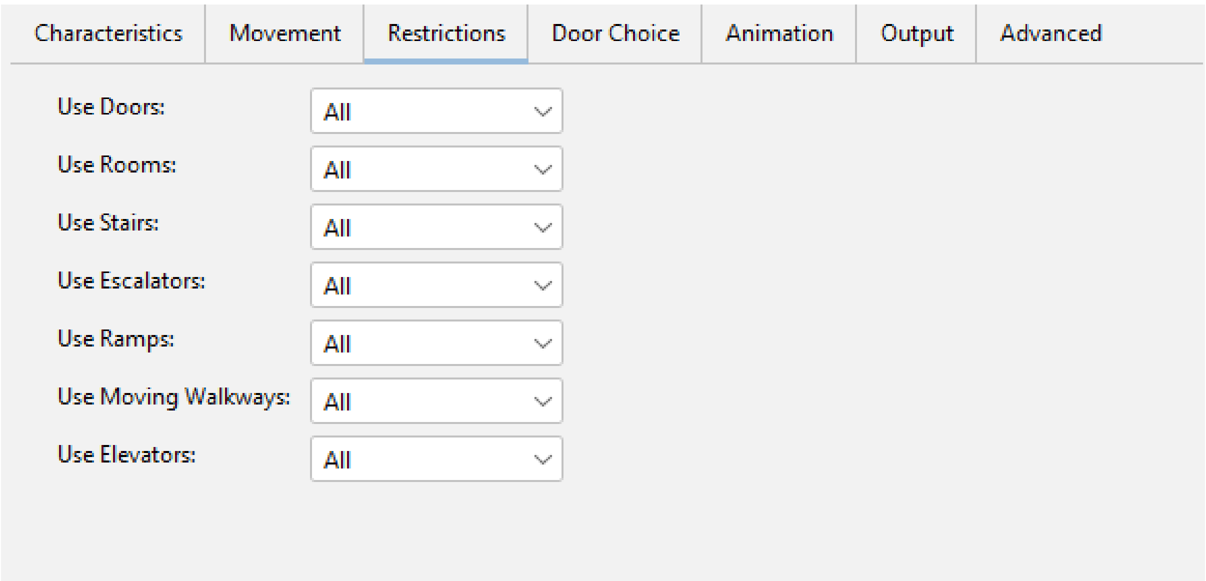

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Use Doors:
From List...
Reject
[none]
Use Rooms:
All
Use Stairs:
All
Use Escalators:
All
Use Ramps:
All
Use Moving Walkways:
All
Use Elevators:
All

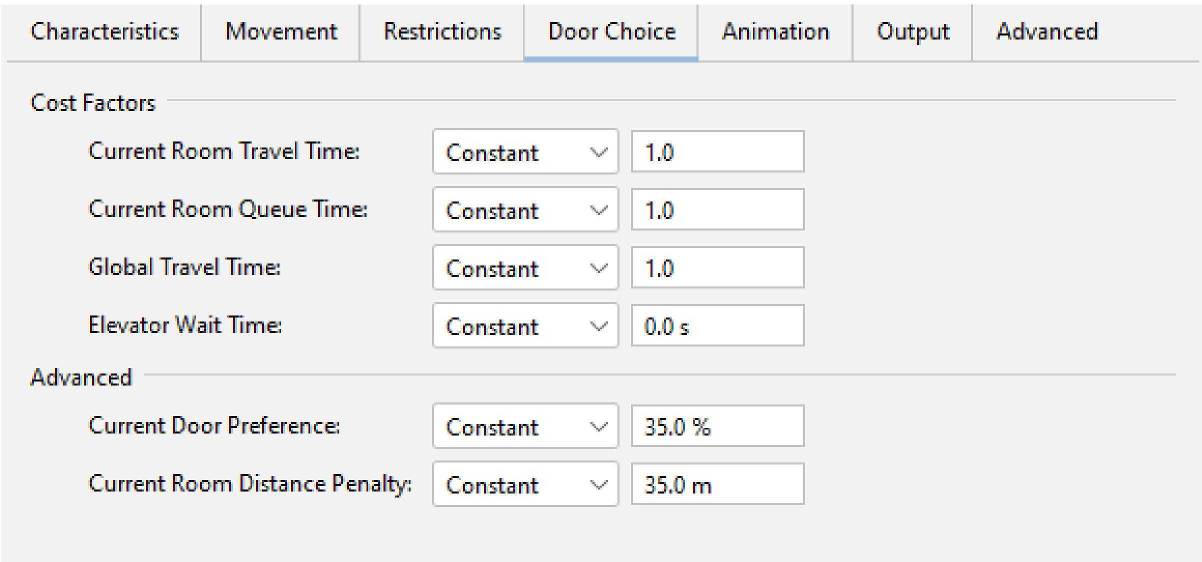

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Cost Factors
Current Room Travel Time:
Constant
1.0
Current Room Queue Time:
Constant
1.0
Global Travel Time:
Constant
1.0
Elevator Wait Time:
Constant
0.0 s
Advanced
Current Door Preference:
Constant
35.0 %
Current Room Distance Penalty:
Constant
35.0 m

Independent Senior Movement Parameters:

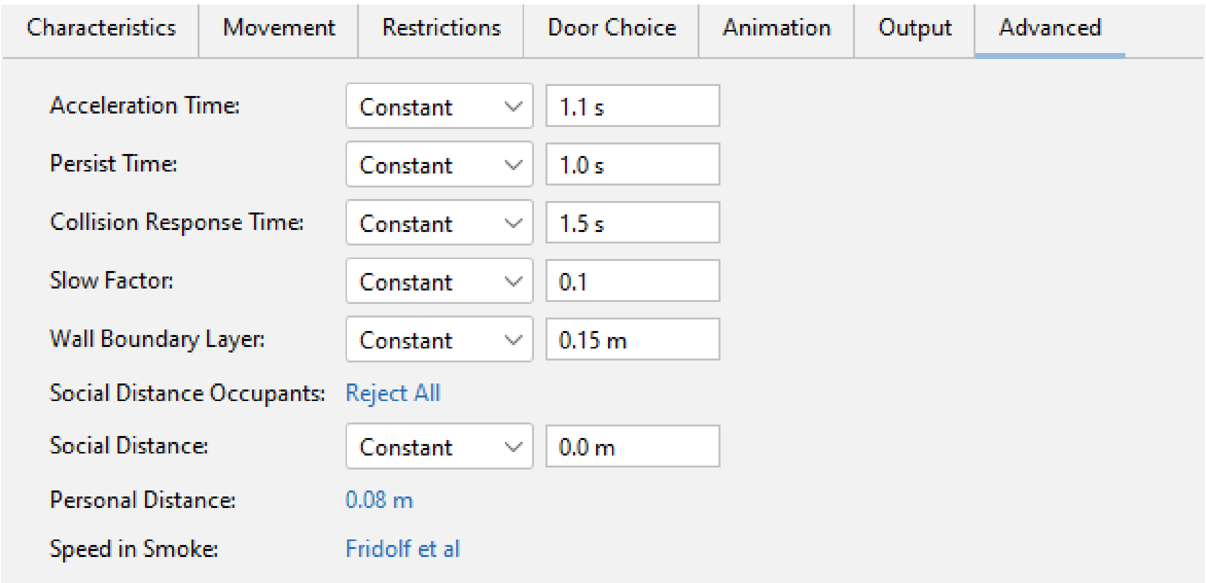


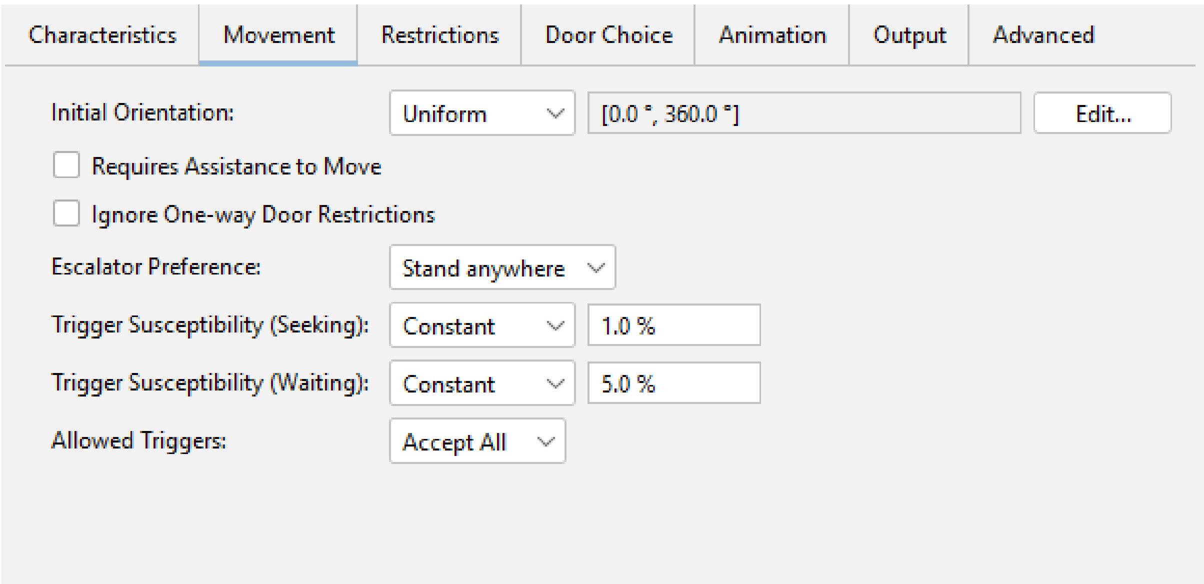


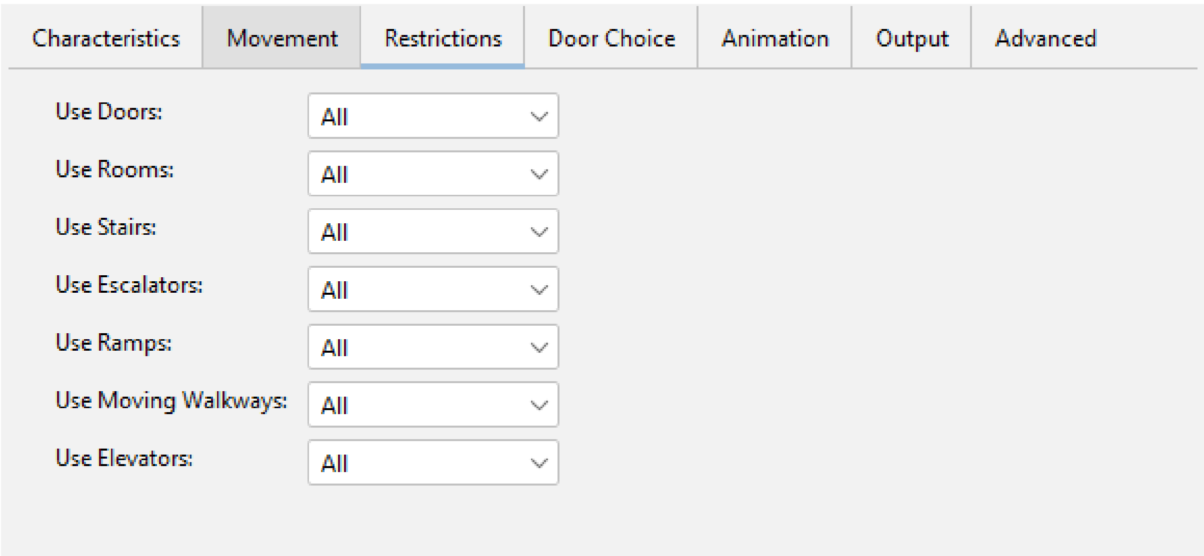


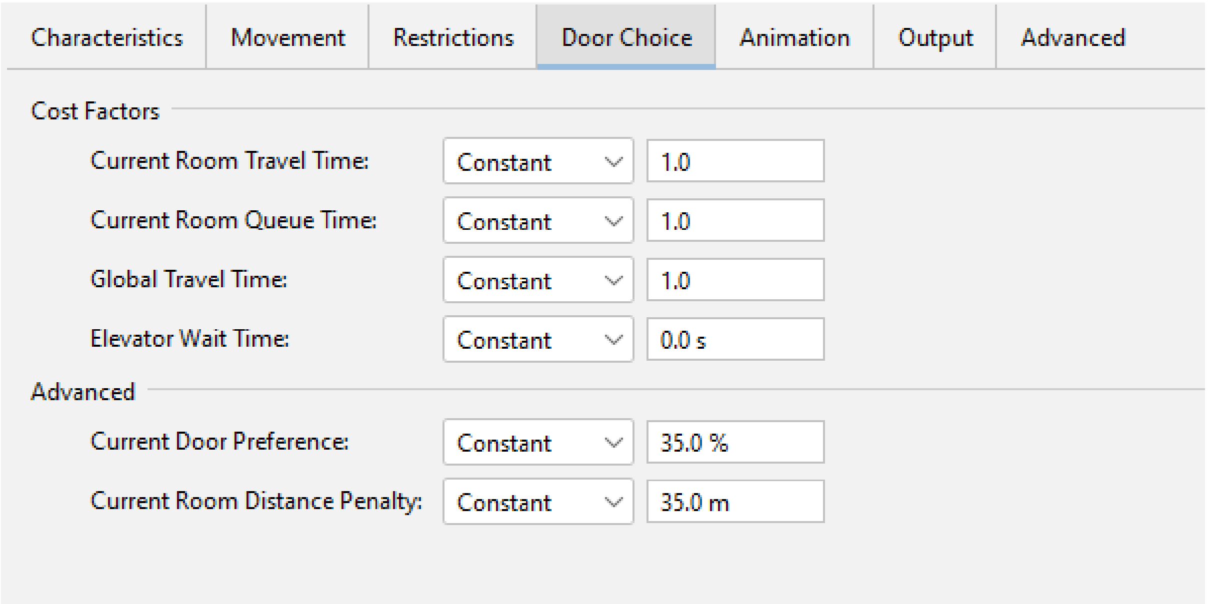


Normal Person Movement Parameters:

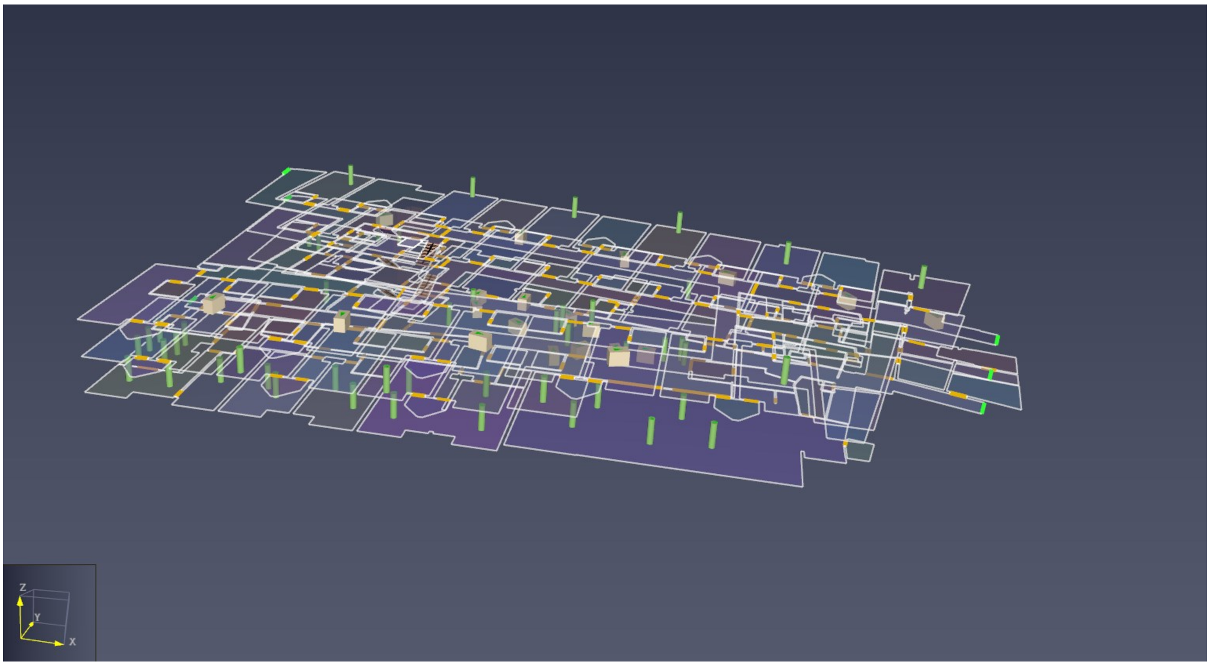

Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Acceleration Time: Constant 1.1 s
Persist Time: Constant 1.0 s
Collision Response Time: Constant 1.5 s
Slow Factor: Constant 0.1
Wall Boundary Layer: Constant 0.15 m
Social Distance Occupants: Reject All
Social Distance: Constant 0.0 m
Personal Distance: 0.08 m
Speed in Smoke: Fridolf et al


Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Initial Orientation: Uniform [0.0 °, 360.0 °] Edit...
Requires Assistance to Move
Ignore One-way Door Restrictions
Escalator Preference: Stand anywhere
Trigger Susceptibility (Seeking): Constant 1.0 %
Trigger Susceptibility (Waiting): Constant 5.0 %
Allowed Triggers: Accept All


Characteristics
Movement
Restrictions
Door Choice
Animation
Output
Advanced
Use Doors: All
Use Rooms: All
Use Stairs: All
Use Escalators: All
Use Ramps: All
Use Moving Walkways: All
Use Elevators: All



Geometry Input:



Appendix Q – Pathfinder Output worst case scenario at 0, 5, 10, 15, and 30 minutes

People in the Building: 69

People Exited the Building: 0

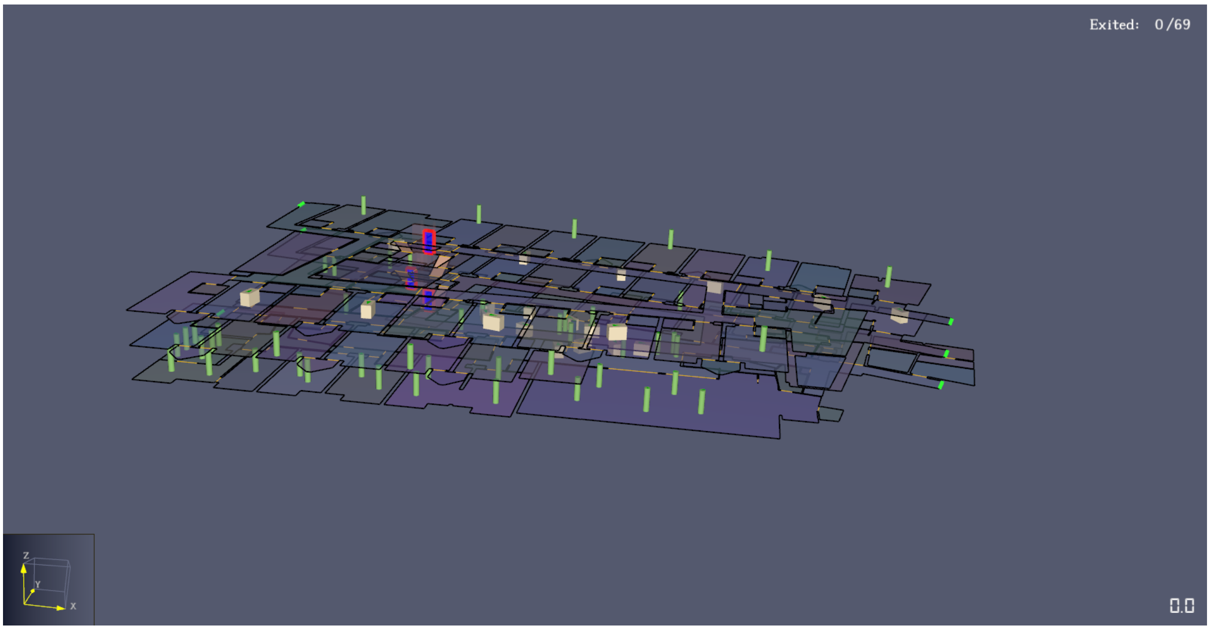


Figure 65: Pathfinder Simulation Results at 0 minutes

People in the Building: 15

People Exited the Building: 54

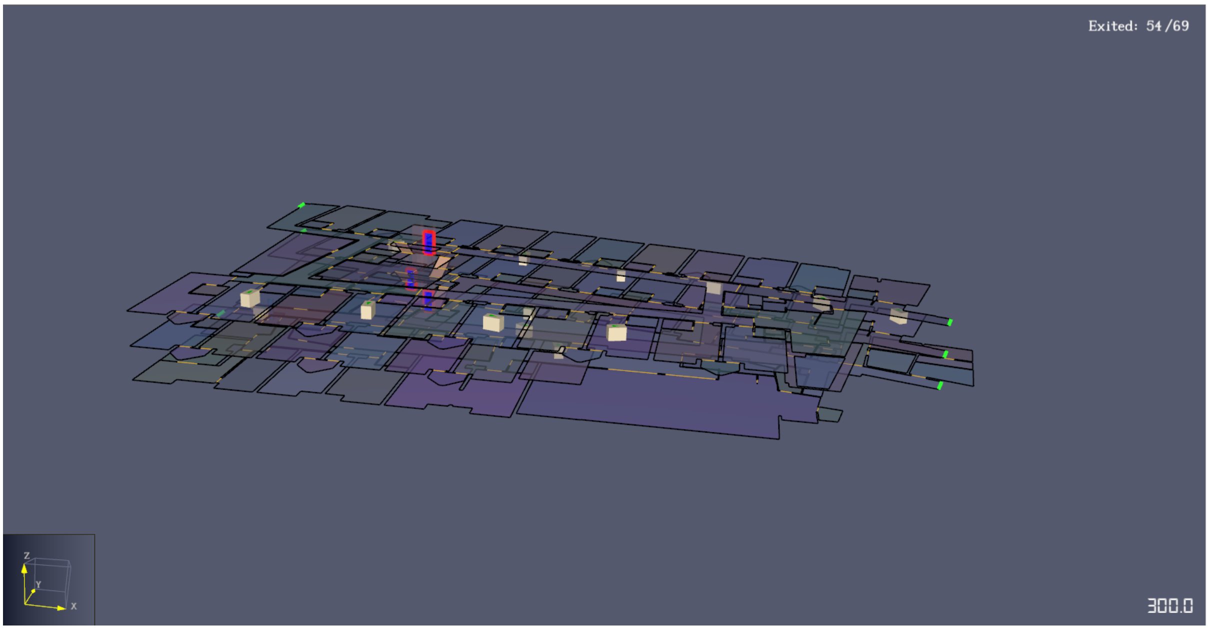


Figure 66: Pathfinder Simulation Results at 5 minutes

People in the Building: 9

People Exited the Building: 60

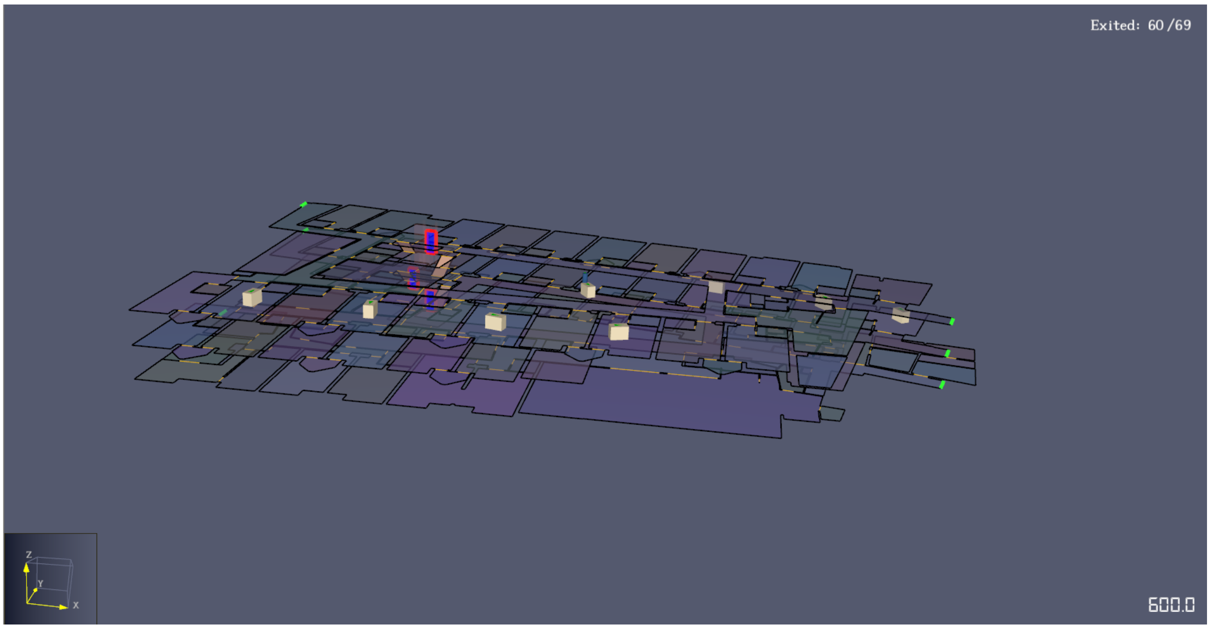


Figure 67: Pathfinder Simulation Results at 10 minutes

People in the Building: 3

People Exited the Building: 66

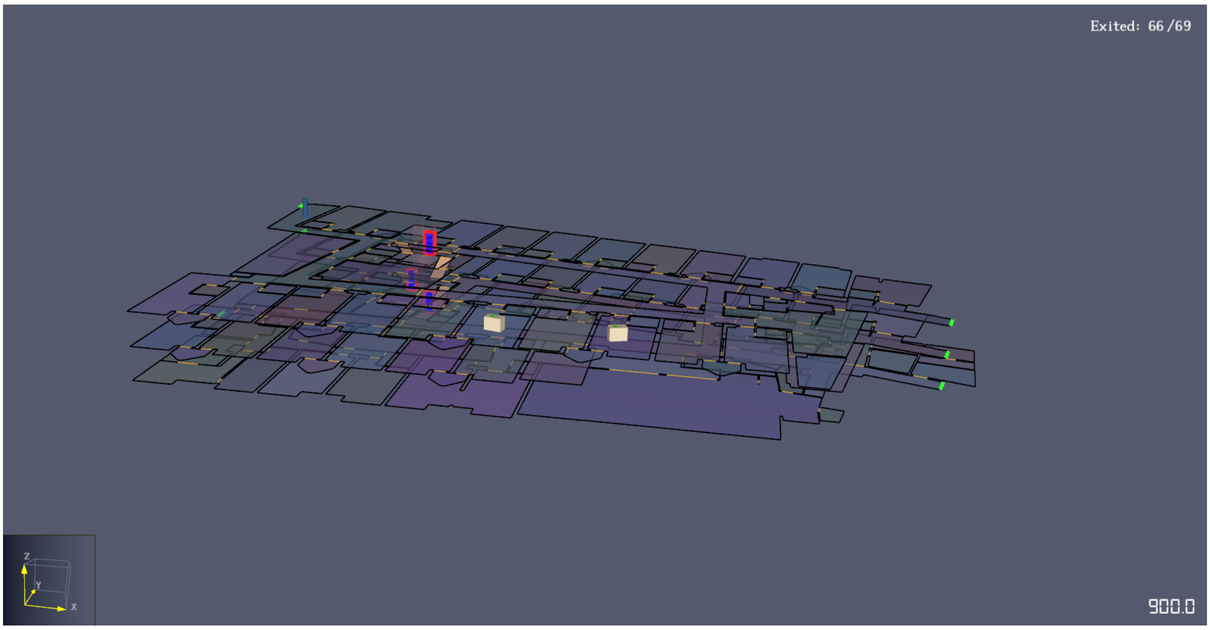


Figure 68: Pathfinder Simulation Results at 15 minutes

People in the Building: 0

People Exited the Building: 69

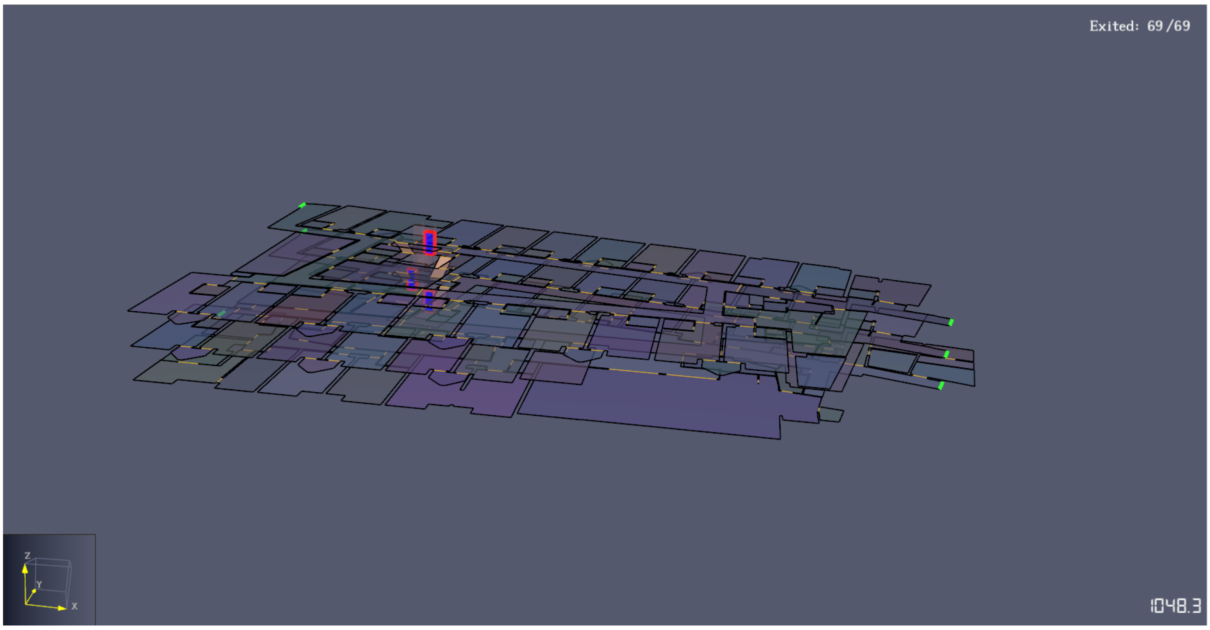


Figure 69: Pathfinder Simulation Results at 17.47 minutes

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