Appendices

Appendix A: Inferential statistics

Let X denote the 'population' of all possible model outcomes having a mean μ, and a standard deviation σ. For instance, this is represented by the population of *all* possible ZETs generated with the mesoscopic model (or at least with a very large number of runs in the order of 10^4 or 10^5). μ, and σ are the population *parameters*, hence fixed unknown numerical values that designers want to estimate.

Since engineers wish to minimise the number of model realizations to reduce the computational cost of egress analyses, a limited number of simulations is typically run, which can be seen as a subset or a 'sample' of observations drawn randomly from the population. In this case, inferential statistics are needed to draw conclusions about the population from the sample characteristics. Let X_1, X_2, …, X_i, …, X_n denote a random sample having a mean $\overline{X}$, and a standard deviation S. These are the sample *statistics*, and the use of uppercase letters highlights that, before sampling, the observations are random variables. After sampling, each observation is a number, denoted by a lowercase letter x_1, x_2, …, x_i, …, x_n. The statistics $\bar{x}$ and s are also numerical values known to designers, as they can be computed from the sampled observations. However, their value may vary from sample to sample. For instance, a sample can be composed of 50 values of ZET determined through 50 model runs, for which it is possible to calculate the mean and the standard deviation. If another sample of 50 ZETs is generated, new values of $\bar{x}$ and s may be found.

As $\overline{X}$ and S are random variables whose values $\bar{x}$ and s depend on the sample, they only represent the best guess of the population parameters μ and σ, but they are never exact. In fact, it can be expected that for some samples the estimate is larger than the true value, and in other cases the contrary occurs. This approximation inevitably generates an error of estimation Δ. Due to the law of large numbers, as the simple size increases, the error of estimation decreases, and the sample statistics tend to the population parameters. Ideally engineers aspire to know the population parameters by running large numbers of simulations, but practically the available resources only allow them to perform a limited number of runs to obtain the sample statistics. Therefore, the sample mean $\overline{X}$ is the *estimator* of the population mean μ, and $\bar{x}$ is the *point estimate* of μ i.e., a single number computed from the sampled data that can be regarded as the most plausible value of μ. Similarly, s is the point estimate that is used to make inferences about σ. Due to this approximation, it is important to quantify the error of estimation.

If the sample size n is sufficiently large, Δ can be estimated with z statistics. In fact, if n > 40 (Devore, 2012), the Central Limit Theorem can be apllied and it is possible to state that the sample mean $\overline{X}$ has approximately a normal distribution regardless of the population distribution X, with an expected value μ and a standard deviation $\sigma/\sqrt{n}$. When $\overline{X}$ is standardized, the random variable $Z = \frac{\overline{X}-\mu}{\sigma/\sqrt{n}}$ is obtained, which has approximately a standard normal distribution.

Based on z statistics, it is now possible to state that:

$$P(-z_{\alpha/2} < Z < z_{\alpha/2}) \approx 1 - \alpha$$ *Equation 15 (Devore, 2012)*

$$P\left(-z_{\alpha/2} < \frac{\overline{X} - \mu}{\sigma/\sqrt{n}} < z_{\alpha/2}\right) \approx 1 - \alpha$$ *Equation 16 (Devore, 2012)*

$$P\left(\overline{X} - z_{\alpha/2}\frac{\sigma}{\sqrt{n}} < \mu < \overline{X} + z_{\alpha/2}\frac{\sigma}{\sqrt{n}}\right) \approx 1 - \alpha$$ *Equation 17 (Devore, 2012)*

As the value of the population standard deviation σ is unknown a priori, Z is typically standardized using the sample standard deviation S instead. Now both $\overline{X}$ and S vary from sample to sample. However, if n is large, S adds negligible variability to Z because s will be close to σ (Devore, 2012). Therefore, it is possible to write:

$$P\left(\overline{X} - z_{\alpha/2}\frac{S}{\sqrt{n}} < \mu < \overline{X} + z_{\alpha/2}\frac{S}{\sqrt{n}}\right) \approx 1 - \alpha$$ *Equation 18 (Devore, 2012)*

After observing $X_1 = x_1$, $X_2 = x_2$, …, $X_n = x_n$ and computing the observed sample mean $\bar{x}$ and standard deviation s, it is possible to rewrite Equation 18 as:

$$P\left(\bar{x} - z_{\alpha/2}\frac{s}{\sqrt{n}} < \mu < \bar{x} + z_{\alpha/2}\frac{s}{\sqrt{n}}\right) \approx 1 - \alpha$$ *Equation 19 (Devore, 2012)*

This represents the large-sample confidence interval for μ $\left(\bar{x} - z_{\alpha/2}\frac{s}{\sqrt{n}};\ \bar{x} + z_{\alpha/2}\frac{s}{\sqrt{n}}\right)$ with a confidence level of approximately 100(1 – α) %. Typical values of α and $z_{\alpha/2}$ are reported in Table 6 for commonly used confidence levels.

Table 6 – Values of α and $z_{\alpha/2}$ for commonly used confidence levels

Confidence level CL	**α**	$\mathbf{z_{\alpha/2}}$
0.80	0.20	1.28
0.85	0.25	1.44
0.90	0.10	1.65
0.95	0.05	1.96
0.98	0.02	2.33
0.99	0.01	2.58

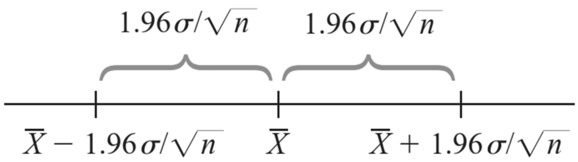


Figure 61 – Representation of a confidence interval centered at $\overline{X}$ with a confidence level of approximately 95%. Figure from (Devore, 2012)

Conceptually, a confidence interval represents a range of plausible values for the parameter being estimated through the sample statistics. The centre of the interval is the sample mean $\bar{x}$ and it extends by the quantity $z_{\alpha/2}\frac{s}{\sqrt{n}}$ on each side. This is often referred as 'standard error' and denoted by Δ. Therefore, it is possible to express the confidence interval alternatively as:

$$\bar{x} - \Delta < \mu < \bar{x} + \Delta \qquad \textit{Equation 20 (Devore, 2012)}$$

$$\mu = \bar{x} \pm \Delta \qquad \textit{Equation 21 (Devore, 2012)}$$

Both the interval center and the error are random variables for each sample. However, when n increases the error reduces. Therefore, it is possible to think at the width of the interval as its accuracy or precision.

The confidence level expresses the probability for the random interval to include the true value of μ. For instance, a 95% confidence level means that if a random sample of size n is generated 100 times, and the confidence interval is computed for each sample, approximately 95 of the intervals will include the true value of the population mean μ (Figure 62). If the confidence level is increased, the value of $z_{\alpha/2}$ also increases and interval becomes wider. Therefore, we can see the confidence level as the reliability of the confidence interval: the higher the confidence level, the more likely it is for the interval to include the population parameter, because it is wider.

As a result, estimating a confidence interval is a compromise between accuracy and reliability: a reliable interval (high confidence level) tends to be imprecise (wide), while a precise (narrow) interval is less reliable (low confidence level). For design purposes, a confidence level of 95% is often chosen. Values of 90% or 99% are also used frequently (Devore, 2012).

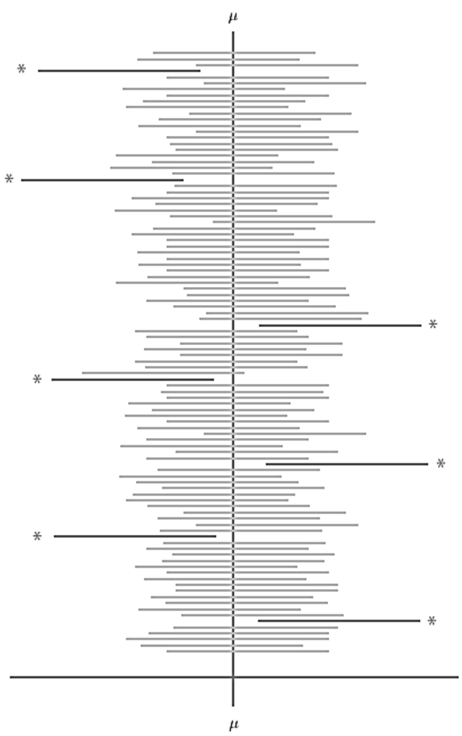


Figure 62 – Representation of one hundred confidence intervals with confidence level of approximately 95%. Asterisks identify intervals that do not include the population mean μ. Figure from (Devore, 2012)

In a similar manner, the sample variance s^2 can be used to draw inferences about the population variance σ^2. When the population has a normal distribution, the chi-squared probability distribution χ^2 having $\nu = n - 1$ degrees of freedom replaces the Z distribution used previously, and it is possible to state that:

$$P\left(\chi^2_{1-\alpha/2,\nu} < \frac{(n-1)S^2}{\sigma^2} < \chi^2_{\alpha/2,\nu}\right) = 1 - \alpha$$ *Equation 22 (Devore, 2012)*

$$\frac{(n-1)s^2}{\chi^2_{\alpha/2,\nu}} < \sigma^2 < \frac{(n-1)s^2}{\chi^2_{1-\alpha/2,\nu}}$$ *Equation 23 (Devore, 2012)*

Equation 23 represents the confidence interval for the variance σ^2 of a normal population with a confidence level $100(1 - \alpha)$ %. The interval for the standard deviation σ can be calculated as:

$$\sqrt{\frac{(n-1)s^2}{\chi^2_{\alpha/2,\nu}}} < \sigma < \sqrt{\frac{(n-1)s^2}{\chi^2_{1-\alpha/2,\nu}}}$$ *Equation 24 (Devore, 2012)*

Appendix B: User manual

This section represents a user manual of the probabilistic mesoscopic model for fire evacuation in large gatherings developed by Lorenzo Contini.

Users are informed that the tool is a prototype that may lack of accuracy in the prediction of real-world phenomena. Expert judgement is necessary to evaluate the appropriateness of its use and its predictive capabilities.

Feedback to the author is encouraged to guide future developments of the tool.

Model setup and deterministic run

The modelling process starts from the sheet named 'Input'. First, compile the sheet with the parameters concerning the characteristics of occupants, zones and nodes.

Inputs for occupants:

– Unimpeded walking speed S_{max}: choose a distribution shape Distr[S_{max}] (Normal by default), and input values for its mean E[S_{max}] and standard deviation Var[S_{max}]$^{1/2}$ in [m/s].

Inputs for zones:

– Component ID: input the letter 'Z' followed by a zone number (e.g., Z1, Z2, Z3, etc.)

– Component type T: input a text description.

– Floor length X and width Y: input values for the dimensions of the zones in [m].

– Path shape PS: choose between 'Diagonal' (shortest distance that represents the absence of obstacles) or 'X+Y' (longer distance that represents the path around obstacles).

– Occupant density D: input a value in [pers/m^2].

– Detection + notification time t_{d+n}: choose a distribution shape Distr[t_{d+n}] (Normal by default), and input values for its mean E[t_{d+n}] and standard deviation Var[t_{d+n}]$^{1/2}$ in [s].

– Pre-evacuation time t_{pre}: choose a distribution shape Distr[t_{pre}] (Log-normal by default), and input values for its location E[t_{pre}] and scale Var[t_{pre}]$^{1/2}$ in [s]. A calculator is available in the same sheet to derive E[t_{pre}] and Var[t_{pre}]$^{1/2}$ from the pre-evacuation times of the 1st and 99th percentiles ($t_{pre,1st}$ and $t_{pre,99th}$).

Inputs for nodes:

– Component ID: input the letter 'N' followed by a node number (e.g., N1, N2, N3, etc.)

– Previous components: input the names of the previous components in the network.

– Component type T: input a text description.

– Measured width W: input a value in [m].

– Boundary layer BL: input a value in [m]. See Table 59.1 in (Gwynne & Rosenbaum, 2016).

– Max specific flow $F_{s,max}$: input a value in [pers/(ms)]. See Table 59.5 in (Gwynne & Rosenbaum, 2016).

- Unimpeded walking speed S_{max}: input a value in [m/s]. See Table 59.4 in (Gwynne & Rosenbaum, 2016).
- Component constant k: input a value. See Table 59.2 in (Gwynne & Rosenbaum, 2016).
- Component length L: enter a value in [m].

Once the inputs have been compiled, update the sheet by pressing F9, and click the button 'Create Network'. A new sheet for every zone/node will be generated. Update again the sheet to perform the calculation of the network using a random sample from input distributions. Every the sheet is updated, a new random sample is generated and a deterministic calculation of the network is performed. The outputs for every zone/node can be found in the respective sheet. The outputs for the whole network can be found in the sheet 'Output'.

If a new network needs to be generated, click the button 'Restore', then repeat the process.

Iterative runs for convergence

After the model has been setup and a deterministic run has been calculated, it is possible to perform and record a number of iterative runs until convergence is reached. To do so, in the sheet named 'Iterations', specify a maximum number of iterations N_{max} (the minimum value is 50). Then choose if the model should stop when convergence is reached.

- If 'NO' is selected, the model performs a number of simulations $n = N_{max}$.
- If 'YES' is selected and convergence is achieved for $n < N_{max}$, the model stops the iterative process; if convergence is not achieved before N_{max}, the model stops anyways when $n = N_{max}$.

  In this second case, after selecting 'YES', go to the sheet named 'Convergence', in the field 'Component ID' choose the first zone of the network, then specify a design confidence level CL and a desired percentile for the calculation of the design evacuation curve. Update 'Convergence' sheet and return to 'Iterations' sheet.

Click the button 'Reiterate'. A new group of lines (outputs for every node/zone) will be recorded in the 'Iterations' sheet for every new model run. To visualise the mean, min, max and design curves go to the sheet 'Convergence', choose the desired component ID and update the sheet.

If new iterations need to be generated, click the button 'Clear', then repeat the process.

Iterative runs for convergence

After convergence runs have been calculated, it is possible to perform and record a number of iterative runs to analyse multiple evacuation scenarios. To do so, in the sheet named 'Bins', specify the scenario matrix.

- Scenario ID: input numbers from 1 to the max number of scenarios (e.g., 1, 2, 3, etc.)
- Description: input a text description.
- Par 1 to 12: specify the parameters that vary in different evacuation scenarios and their values. Update the sheet. Then link the cells in the 'Input' sheet to the corresponding cells in the 'Bins' sheet (range R6:R17). Update the sheet.

In the sheet ‘Scenarios’ click the button ‘Calculate scenarios’. A new group of lines (design curves for every zone/node) will be recorded in the ‘Scenarios’ sheet for every new scenario. To visualise the groups of curves generated for every zone/node of the network go to the sheet ‘Consequences’, choose the desired component ID and update the sheet.

If new scenarios need to be generated, click the button ‘Clear’, then repeat the process.

Appendix C: Test scenarios – Setup of the evacuation models

All scenarios

UNIMPEDED WALKING SPEED			
Distribution	$Distr[S_{max}]$	-	Normal
Mean	$E[S_{max}]$	m/s	1.19
Standard deviation	$Var[S_{max}]^{1/2}$	m/s	0.30

Scenario T1_A

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T1_B

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T1_C

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	1.0	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T1_D

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	1.0	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T1_E

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	2.0	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T1_F

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	2.0	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T2_A

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Corridor	4.00	0.40	1.316	1.19	1.40	30.0	
N3	N2	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T2_B

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Corridor	4.00	0.40	1.316	1.19	1.40	30.0	
N3	N2	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T2_C

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Corridor	2.00	0.40	1.316	1.19	1.40	30.0	
N3	N2	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T2_D

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Corridor	2.00	0.40	1.316	1.19	1.40	30.0	
N3	N2	0	Door	1.00	0.30	1.316	1.19	1.40	0.0	

Scenario T3

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Transit	30.00	0.40	1.316	1.19	1.40	15.0	
N3	N2	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T4_A

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Landing	4.00	0.40	1.316	1.19	1.40	2.0	
N3	N2	0	Stair	4.00	0.30	0.940	0.85	1.00	7.0	
N4	N3	0	Landing	4.00	0.40	1.316	1.19	1.40	2.0	
N5	N4	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T4_B

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	$pers/m^2$	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Landing	2.00	0.40	1.316	1.19	1.40	2.0	
N3	N2	0	Stair	2.00	0.30	0.940	0.85	1.00	7.0	
N4	N3	0	Landing	2.00	0.40	1.316	1.19	1.40	2.0	
N5	N4	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T4_C

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Landing	4.00	0.40	1.316	1.19	1.40	2.0	
N3	N2	0	Stair	4.00	0.30	1.160	1.05	1.23	7.0	
N4	N3	0	Landing	4.00	0.40	1.316	1.19	1.40	2.0	
N5	N4	0	Door	4.00	0.30	1.316	1.19	1.40	0.0	

Scenario T4_D

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room	30.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Landing	2.00	0.40	1.316	1.19	1.40	2.0	
N3	N2	0	Stair	2.00	0.30	1.160	1.05	1.23	7.0	
N4	N3	0	Landing	2.00	0.40	1.316	1.19	1.40	2.0	
N5	N4	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T5_A

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	$Distr[t_{d+n}]$	$E[t_{d+n}]$	$Var[t_{d+n}]^{1/2}$	$Distr[t_{pre}]$	$E[t_{pre}]$	$Var[t_{pre}]^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room 1	15.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27
Z2	Room 2	15.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Transit	15.00	0.40	1.316	1.19	1.40	17.0	
N3	Z2	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N4	N3	0	Transit	15.00	0.40	1.316	1.19	1.40	17.0	
N5	N2	N4	Merging point	15.00	0.40	1.316	1.19	1.40	0.0	
N6	N5	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Scenario T5_B

ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$		Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Room 1	15.0	15.0	Diagonal	0.5	Normal	0	0	Log-normal	4.21	0.27
Z2	Room 2	15.0	15.0	Diagonal	0.5	Normal	90	0	Log-normal	4.21	0.27

NODES										N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N2	N1	0	Transit	15.00	0.40	1.316	1.19	1.40	17.0	
N3	Z2	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	
N4	N3	0	Transit	15.00	0.40	1.316	1.19	1.40	17.0	
N5	N2	N4	Merging point	15.00	0.40	1.316	1.19	1.40	0.0	
N6	N5	0	Door	2.00	0.30	1.316	1.19	1.40	0.0	

Appendix D: Case study – Modelling assumptions and inputs

D.1 Design scenarios

D.1.1 Fire characteristics

Since the objective of the analysis is life safety of occupants, design fires are assumed to be in the pre-flashover stage. This is assumed to grow at a quadratic rate (HRR = $\alpha_g t^2$).

The walls, the floors and the ceilings of the facility are made of incombustible materials. Thus, the majority of the fuel load is represented by the furniture in the dining areas (e.g., tables and chairs) and the combustible materials in the kitchens (e.g., food, oils and fats, packaging, etc.). Therefore, two types of fires are identified as representative for the food court: kitchen fires, which can originate in the food preparation areas located along the perimeter of the facility, and furniture fires that can originate in the dining areas.

In both cases a medium fire growth rate is considered (α_g = 0.011 kW/s^2) until a peak heat release of 5000 kW is reached. The combustion reaction of a generic fuel $CH_2O_{0.5}$ is assumed to occur with a heat of combustion ΔH_c = 20 MJ/kg, a radiative fraction χ_r = 0.35 and a soot yield y_s = 0.07 kg/kg (Italian Fire Safety Code, 2019).

Since food preparation areas are protected by an automatic suppression system, it is assumed that the growth of kitchen fires is controlled when a temperature sensing element activates the discharge of the extinguishing agent (despite it is likely that the system will suppress the fire).

D.1.2 Building characteristics

The detection time t_d of the automatic smoke detection system is estimated with the two-zone model CFAST 7.6.0 developed by NIST (Peacock et al., 2015). A point smoke detector is located below the ceiling at an elevation of 4 m and radial distance of 7 m the fire. It is assumed that the smoke detector activates when the obscuration per unit length rises above a value of 20 %/m. The initial ambient temperature is set at 20 °C. The detection time obtained with the fire simulation is t_d = 60 s. The notification time is set as t_n = 0 s since it is assumed that the fire alarm is activated automatically throughout the enclosure as soon as smoke is detected. Therefore t_{d+n} = 60 s.

If the automatic detection and alarm system fails, it is assumed that some occupants become aware of the emergency when the smoke produced by a fire at one end of the enclosure has traversed the entire length of the space. It is assumed that 60 s are necessary for a stable ceiling jet to form. Considering a ceiling jet velocity u = 1 m/s and a maximum ceiling length of about 50 m, the smoke traverse time can be assumed to be 50 s. Therefore, t_d = 60 + 50 = 110 s. Next, it is estimated that a notification time t_n = 60 s is required for the first occupants who perceive the smoke to reach a manual push button or inform directly other occupants. Hence, in case of failure of the automatic detection and notification system, it is assumed t_{d+n} = 110 + 60 = 170 s.

The activation time of the suppression system t_a is also calculated with CFAST, introducing a temperature sensing element above the burner. It is assumed that fast response heat sensing elements are installed, characterised by a RTI of 50 (ms)$^{0.5}$ and an activation temperature of 74 °C. The activation time obtained with the zone model is t_a = 160 s. Conservatively, it is assumed that the automatic system controls the fire without suppressing it. Therefore, after t_a, it is assumed that the fire burns with a steady heat release rate $HRR(t_a) \approx 285$ kW.

D.1.3 Occupants' characteristics

The unimpeded walking speed and the pre-evacuation time are assumed to have the same distributions presented in section 5.1. In case of failure of the automatic detection and alarm system, the distribution of t_{pre} is assumed to be wider, with the values of the 1st and 99th percentiles corresponding respectively to 60 and 240 s (ISO TR 16738 : 2009). This corresponds to lognormal distribution with a location of 4.79 and a scale of 0.23.

The occupant load is expected to vary accordingly to the time of the day. The distribution is estimated using aggregated and anonymized data collected by Google, publicly available on www.google.com. The usage of similar facilities located into the analysed train station on an average day of the week is shown in Figure 63. The same shape is used in this study, assuming that the peak corresponds to a conservative occupant density of 1.0 pers/m^2 (the design value suggested in (Italian Fire Safety Code, 2019) for restaurants is 0.7 pers/m^2). The occupant load in other hours of the day is scaled accordingly. Based on this distribution, five levels of occupant load are selected for egress analyses, and the associated probability is calculated as shown in Table 7. Before ignition, occupants are assumed to be distributed uniformly within the facility.

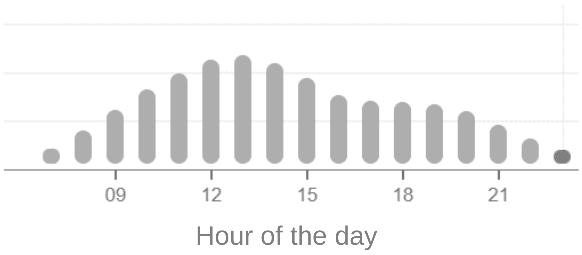


Figure 63 – Case study – Customer visits to similar facilities located in the analysed train station. Figure from www.google.com

Table 7 – Case study – Design occupant loads and associated probability

Density level	**Occupant density [pers/m^2]**	**Probability**
Very low	0.2	0.11
Low	0.4	0.18
Medium	0.6	0.35
High	0.8	0.18
Very high	1.0	0.18

D.2 Fire scenarios

The two types of fires (kitchen and furniture) may originate at any of the three floors of the facility. For model testing, only a kitchen fire located at the ground floor is considered further.

Based the activation/failure of the smoke and heat control system and automatic suppression system, four design fire scenarios are considered as presented in Table 8.

Occupants are deemed incapacitated when the smoke layer reaches an elevation of 2 m above the floor level or a temperature of 200 °C. Therefore, three values of ASET are calculated, corresponding to the time required for smoke to generate untenable conditions at the second floor, the first floor, and the ground floor (called respectively $ASET_2$, $ASET_1$ and $ASET_0$).

Table 8 – Case study – Design fire scenarios

Fire scenario	Type of fire	Location	α_g [kW/s²]	SHC activates	FS activates	HRR_{max} [kW]
F01	Kitchen	GF	0.0111	Yes	Yes	285
F02	Kitchen	GF	0.0111	Yes	No	5000
F03	Kitchen	GF	0.0111	No	Yes	285
F04	Kitchen	GF	0.0111	No	No	5000

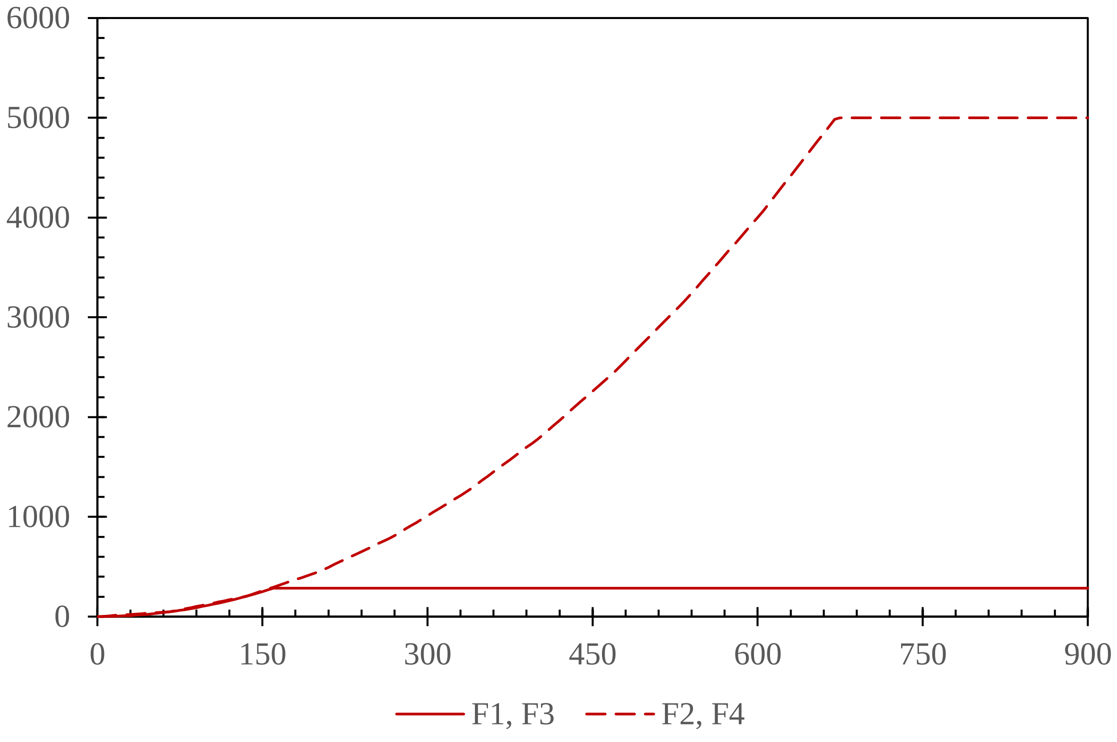


Figure 64 – Case study – Heat release rate curves

D.3 Evacuation scenarios

Based the activation/failure of the automatic smoke detection and notification system, the initial occupant load, and the reactivity of occupants, ten evacuation scenarios are considered as presented in Table 9. The timelines of the initial phases of the evacuation process in case of activation/failure of the SDN system are presented in Figure 65 and Figure 66.

In every case, it is assumed that when a fire is notified (automatically or manually) evacuation proceeds simultaneously at all floors. Conservatively, the main entrance (door n. 1) is discarded (e.g., blocked by the fire) and the occupants at the ground floor are assumed to distribute evenly across the remaining exits. It is assumed that occupants of the first floor split between the stair leading to the ground floor and exit n. 8. Since this door is not used by visitors in ordinary conditions, a proportion of 75% (stair) and 25% (exit) is considered to account for affiliation to familiar areas of the facility. All the occupants of the second floor use the stair as it is the only available egress path. It is assumed that all the occupants arriving at the ground floor from the stair will complete evacuation using exit n. 3, as it is the closest and most visually accessible.

Occupants are deemed safe when they have traversed a door leading to the exterior or to adjacent areas of the train station. Moreover, the occupants initially located at the first and second floor are deemed temporarily safe when they have moved to the lower floor. Therefore, three values of RSET need to be calculated, corresponding to the time required to evacuate the second floor, the first floor, and the ground floor (called respectively $RSET_2$, $RSET_1$ and $RSET_0$).

Table 9 – Case study – Design evacuation scenarios

Evacuation scenario	**Detection + notification time [s]**	**Location of pre-evac time [s]**	**Scale of pre-evac time [s]**	**Occupant density [pers/m^2]**
E01	60	4.21	0.27	0.2
E02	60	4.21	0.27	0.4
E03	60	4.21	0.27	0.6
E04	60	4.21	0.27	0.8
E05	60	4.21	0.27	1.0
E06	170	4.79	0.23	0.2
E07	170	4.79	0.23	0.4
E08	170	4.79	0.23	0.6
E09	170	4.79	0.23	0.8
E10	170	4.79	0.23	1.0

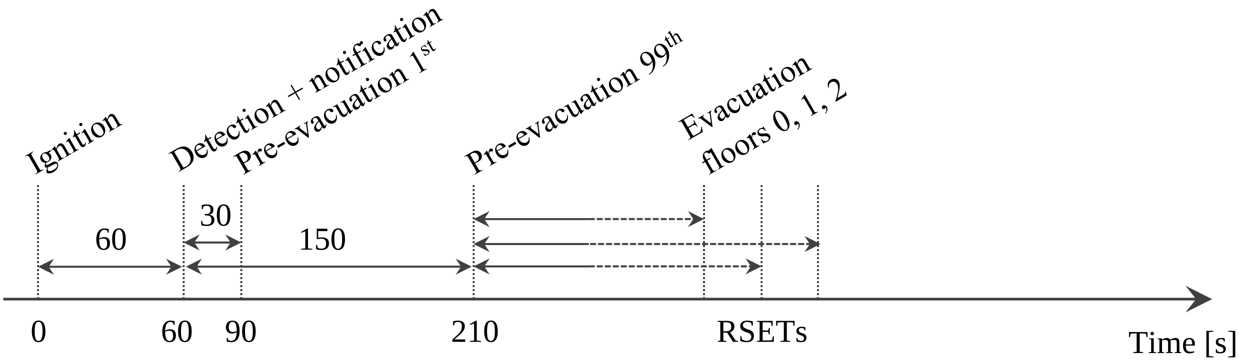


Figure 65 – Case study – Timeline of the evacuation process in case of success of the automatic detection and notification system

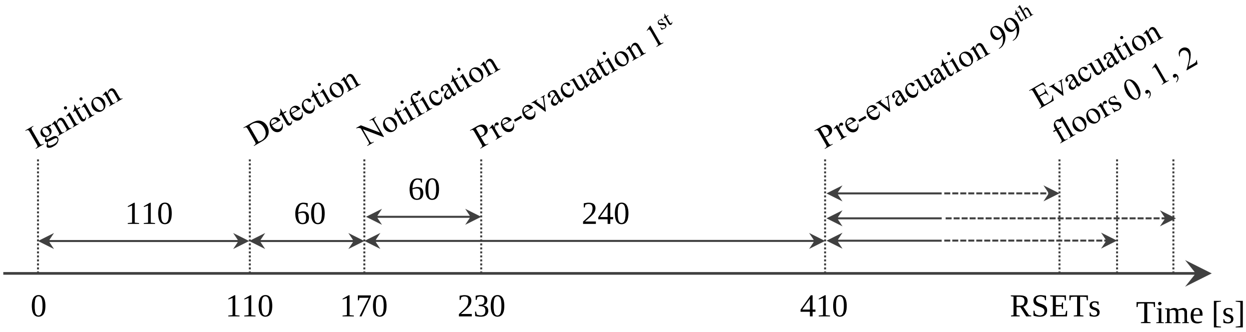


Figure 66 – Case study – Timeline of the evacuation process in case of failure of the automatic detection and notification system

Appendix E: Case study – Fire modelling

The evolution of the smoke layer properties is predicted with the two-zone model CFAST 7.6.0 developed by NIST (Peacock et al., 2015).

The modelled domain coincides with the internal gross volume of the enclosure. This is schematised as two interconnected rooms, without modelling explicitly the first and second floor (Figure 67). In fact, as these areas are completely open towards ground floor, hence it is expected that smoke dynamics are not affected greatly by the presence of the two floor slabs. As a result, when smoke progressively fills the enclosure, it initially engulfs the second floor, then the first floor, and ultimately the ground floor.

The thermal properties of lightweight concrete are applied to the walls: thickness t = 15 cm, thermal conductivity k = 1.75 W/(m K), density ρ = 2200 kg/m^3, specific heat c = 1 kJ/(kg K), emissivity ε = 0.94. Ambient temperature is set at 20 °C.

The burner is placed at the centre of the ground floor, in the area with the greatest internal height. The four scenarios summarised in Table 8 are modelled. In scenarios F01 and F02 the smoke and heat control system activates after 60 s (detection time) and reaches the maximum extraction capacity of 16 m^3/s after additional 30 s. In the same timeframe doors n. 2, 3, 4 and 5 open automatically to allow the inflow of fresh air.

The results show that the smoke layer temperature remains well below 200 °C for the duration of the whole simulations (Figure 68). Therefore, the smoke layer height is the controlling criterion for ASET. Its values obtained for every floor of the facility in each fire scenario are derived from Figure 69 as summarised in Table 10.

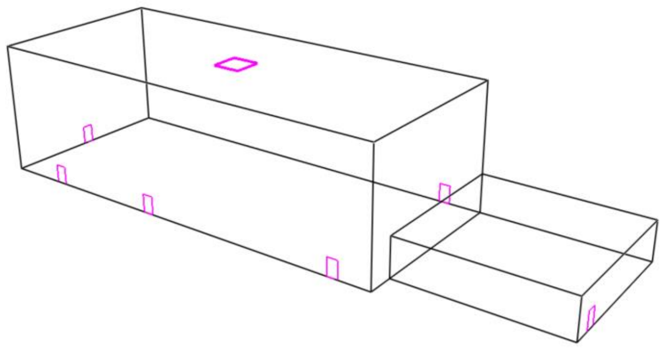


Figure 67 – Case study – 3D view of CFAST model

Table 10 – Case study – ASETs obtained with CFAST

	F01	F02	F03	F04
$ASET_2$ (+ 11.2 m) [s]	350	265	185	175
$ASET_1$ (+ 6.8 m) [s]	> 900	530	475	370
$ASET_0$ (+ 2.0 m) [s]	> 900	> 900	> 900	750

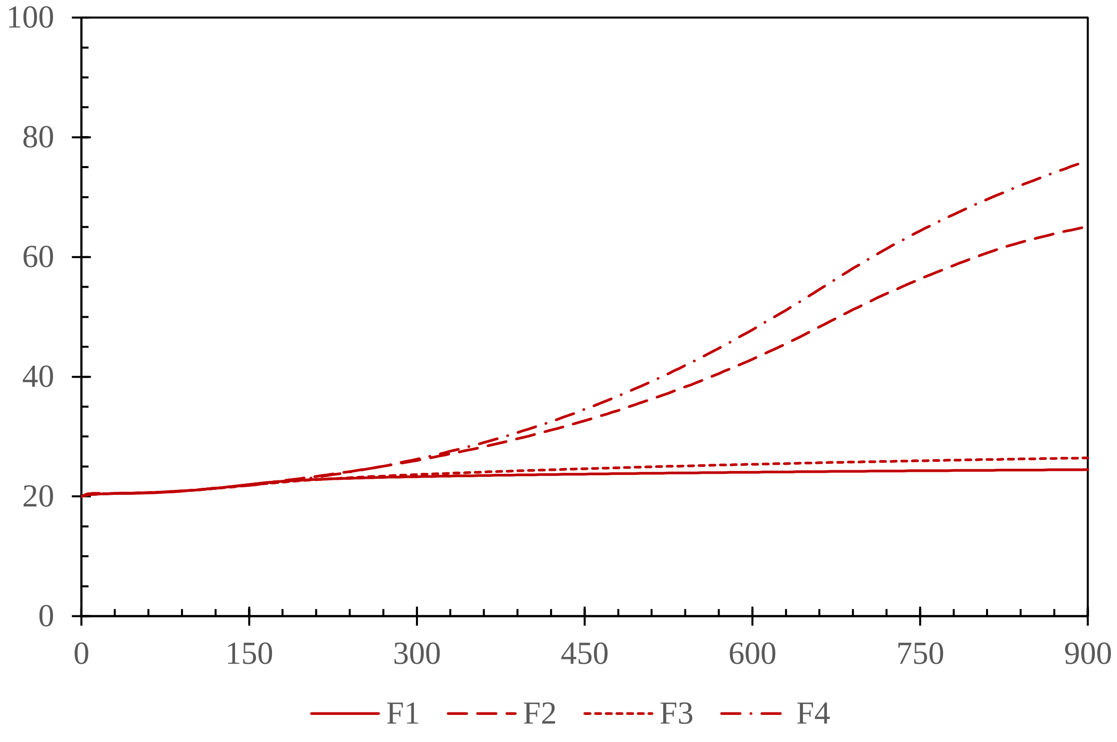


Figure 68 – Case study – Smoke layer temperature obtained with CFAST

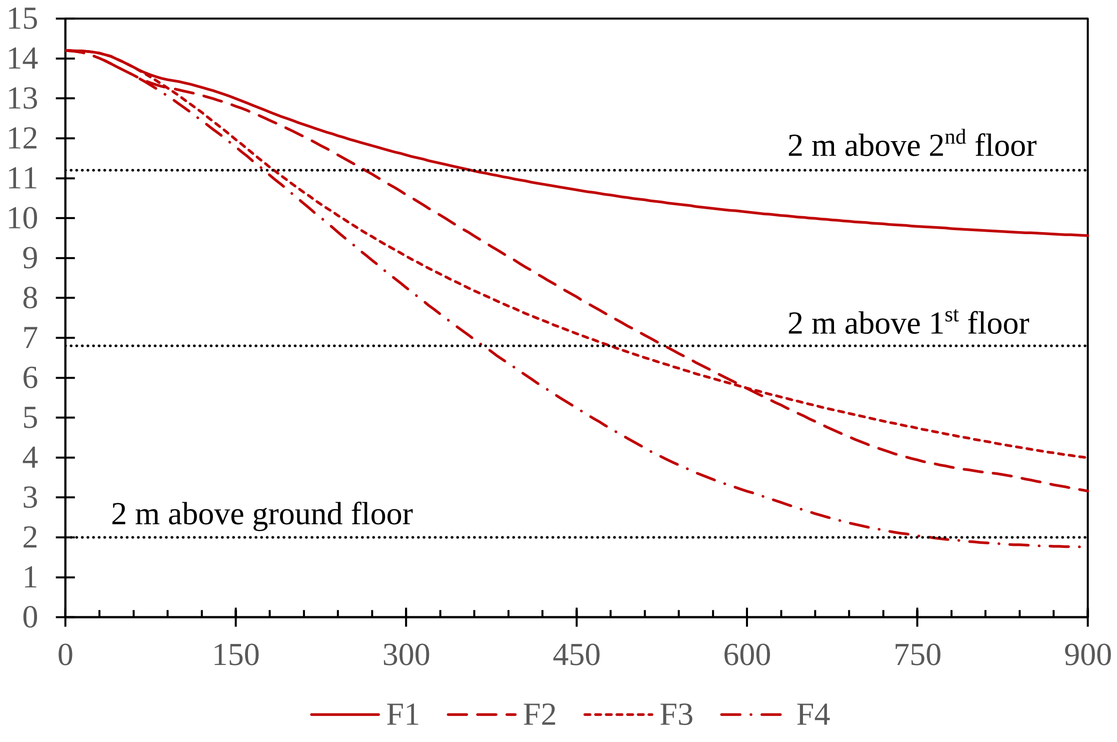


Figure 69 – Case study – Smoke layer height obtained with CFAST

Appendix F: Case study – Setup of the evacuation models

This appendix describes how the case study is modelled in Pathfinder and in the proposed mesoscopic model.

The geometry generated with Pathfinder consists of three rooms, each corresponding to one floor of the facility, located at an elevation of ± 0.0 m, + 4.8 m and + 9.2 m. Only the circulation and food consumption areas accessible to the public are modelled. The kitchens are not included in the model as they have independent exits towards a safe place; therefore, the evacuation of the vendors does not affect the evacuation of the customers. The footprint of obstructions such as counters and furniture is subtracted from the room surface. The three rooms are connected by a stair composed of multiple flights. The width is 150 cm, with risers of 16.5 cm and treads of 30.5 cm. All the doors are modelled 'always open' except for the main entrance which is discarded. Every door width is 120 cm. Figure 70 and Figure 71 provide a 3D and 2D visualization of the described geometry.

When the proposed mesoscopic model is used, the building is represented by 8 zones: 1 at the second floor, 2 at the first floor, and 5 at the ground floor. Only the dimensions of the circulation and food consumption areas are considered. However, since zones are defined as rectangles, an approximation is sometimes necessary to represent the parts of the building that are not perfectly rectangular (Figure 72). The presence of obstructions is considered by setting a 'x+y' type of path shape (section 4.1.2). A total of 24 nodes is generated to represent doors, passageways, corridors, transits, and merging points. They are characterised by the geometrical dimensions described previously, and the component properties summarised in Table 1 and Table 5. Zones and nodes are then combined into 6 networks, each leading to one of the six available final doors, as presented in the following images.

In pathfinder, occupants are randomly scattered over the room surfaces with a density of 1.0 pers/m^2. Thus, the resulting number of occupants generated at the ground, first and second floor is respectively of 600, 230, and 130 pers. In the proposed model, the same density is considered, but a reduction coefficient is introduced to account for the footprint of obstructions and obtain the same initial number of occupants. Their behaviour is set according to the evacuation scenarios presented in Annex D.

F.1 Pathfinder model

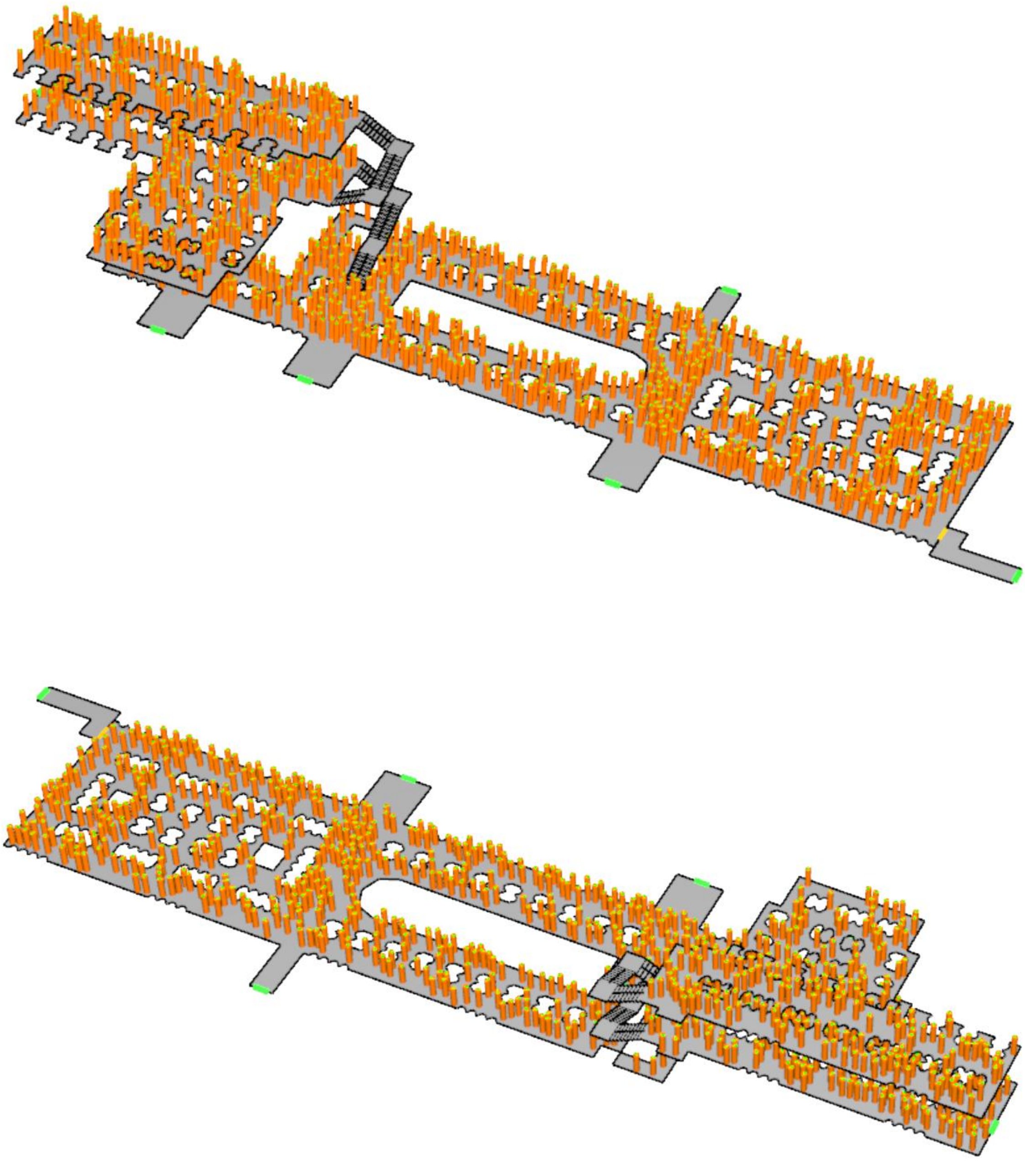
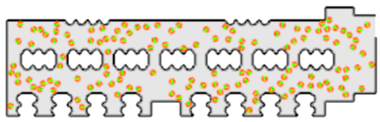
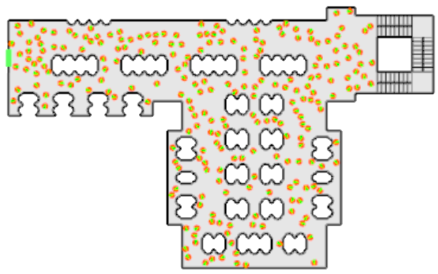


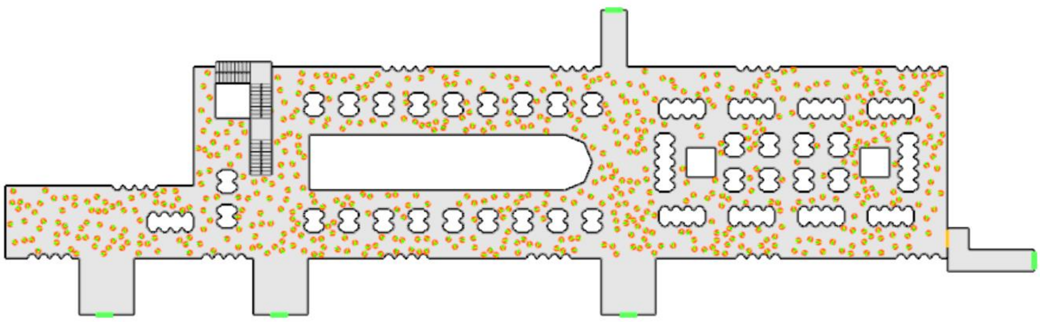
Figure 70 – Case study – 3D views of Pathfinder model



SECOND FLOOR (+ 9.2 m)



FIRST FLOOR (+ 4.8 m)



GROUND FLOOR (± 0.0 m)

Figure 71 – Case study – 2D views of Pathfinder model

F.2 Mesoscopic model

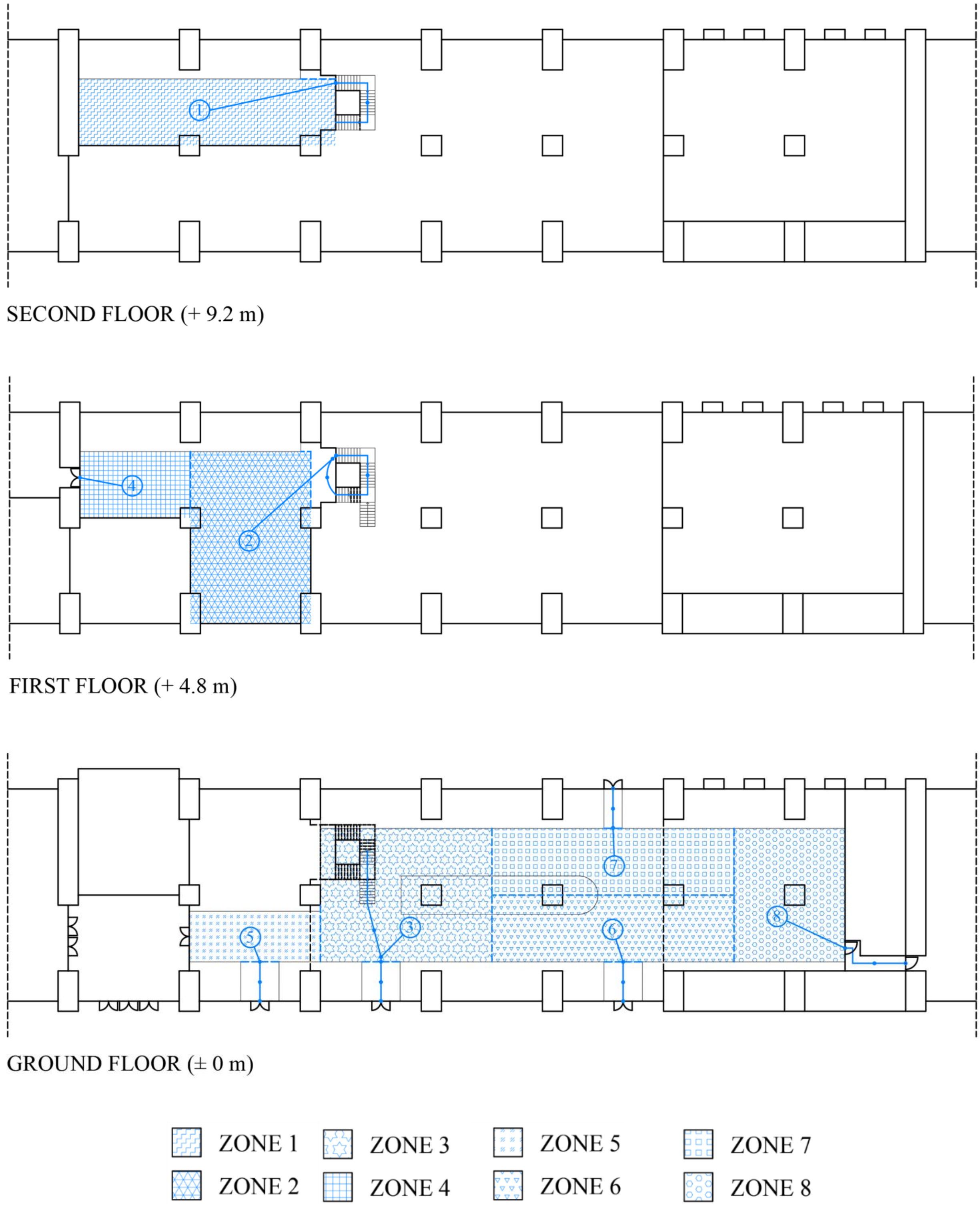
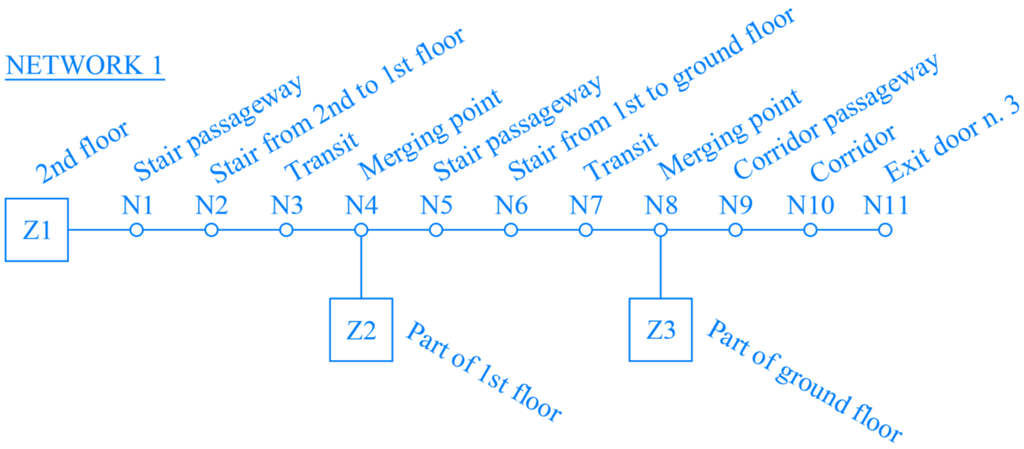


Figure 72 – Case study – Simplification of the building geometry into zones and nodes

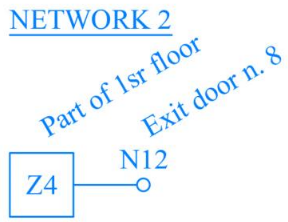
Network 1



ZONES										N of zones	3
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z1	Zone 1	25.5	6.5	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27
Z2	Zone 2	12.0	17.0	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27
Z3	Zone 3	17.0	17.0	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	11
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N1	Z1	0	Passageway	1.50	0.30	1.090	1.00	1.16	0.0	
N2	N1	0	Stair	1.50	0.30	1.090	1.00	1.16	11.5	
N3	N2	0	Transit	1.50	0.30	1.316	1.19	1.40	6.0	
N4	N3	Z2	Merging	1.50	0.30	1.316	1.19	1.40	0.0	
N5	N4	0	Passageway	1.50	0.30	1.090	1.00	1.16	0.0	
N6	N5	0	Stair	1.50	0.30	1.090	1.00	1.16	11.5	
N7	N6	0	Transit	10.00	0.30	1.316	1.19	1.40	5.0	
N8	N7	Z3	Merging	10.00	0.30	1.316	1.19	1.40	0.0	
N9	N8	0	Passageway	5.00	0.30	1.316	1.19	1.40	0.0	
N10	N9	0	Corridor	5.00	0.30	1.316	1.19	1.40	4.0	
N11	N10	0	Exit n. 3	1.20	0.30	1.316	1.19	1.40	0.0	

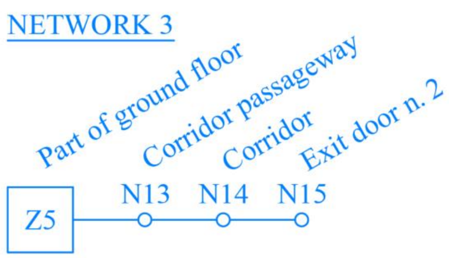
Network 2



ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z4	Zone 4	6.5	11.0	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	1
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N12	Z4	0	Exit n. 8	1.20	0.30	1.316	1.19	1.40	0.0	

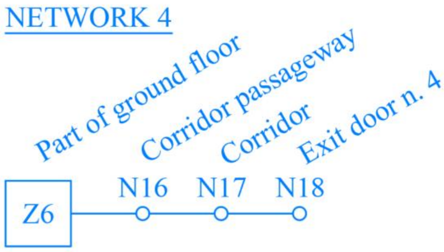
Network 3



ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z5	Zone 5	13.0	5.0	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	3
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N13	Z5	0	Passageway	3.80	0.30	1.316	1.19	1.40	0.0	
N14	N13	0	Corridor	3.80	0.40	1.316	1.19	1.40	4.0	
N15	N14	0	Exit n. 2	1.20	0.30	1.316	1.19	1.40	0.0	

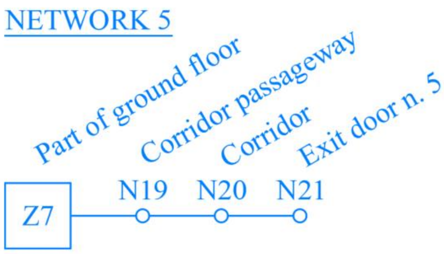
Network 4



ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z6	Zone 6	24.0	5.5	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	3
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N16	Z6	0	Passageway	3.80	0.30	1.316	1.19	1.40	0.0	
N17	N16	0	Corridor	3.80	0.40	1.316	1.19	1.40	4.0	
N18	N17	0	Exit n. 4	1.20	0.30	1.316	1.19	1.40	0.0	

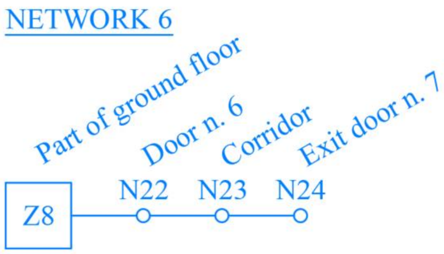
Network 5



ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z7	Zone 7	24.0	5.5	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	3
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N19	Z7	0	Passageway	1.80	0.30	1.316	1.19	1.40	0.0	
N20	N19	0	Corridor	1.80	0.40	1.316	1.19	1.40	4.0	
N21	N20	0	Exit n. 5	1.20	0.30	1.316	1.19	1.40	0.0	

Network 6



ZONES										N of zones	1
Component ID	Component type	Floor length (side with door)	Floor width	Path shape	Occupant density	Detection + notification time	$t_{d+n} = t_d + t_n$	15	Pre-evacuation time	t_{pre}	
-	T	X	Y	PS	D	Distr[t_{d+n}]	E[t_{d+n}]	Var[t_{d+n}]$^{1/2}$	Distr[t_{pre}]	E[t_{pre}]	Var[t_{pre}]$^{1/2}$
-	-	m	m	-	pers/m^2	-	s	s	-	s	s
Z8	Zone 8	11.0	13.0	X+Y	1.0	Normal	60	0	Log-normal	4.21	0.27

NODES									N of nodes	3
Component ID	Previous components		Component type	Measured width	Boundary layer	Max specific flow	Unimpeded walking speed	Component constant	Component length	
-	A	B	T	W	BL	$F_{s,max}$	S_{max}	k	L	
-	-	-	-	m	m	pers/(m·s)	m/s	-	m	
N22	Z8	0	Door	1.20	0.30	1.316	1.19	1.40	0.0	
N23	N22	0	Corridor	1.50	0.40	1.316	1.19	1.40	7.5	
N24	N23	0	Exit n. 7	1.20	0.30	1.316	1.19	1.40	0.0	

Appendix G: Case study – Quantitative risk assessment

Table 11 – Case study, Network 1 – Consequences of risk scenarios

Risk scenario S_i [-]	Fire scenario F_i [-]	Available Safe Egress Time $ASET_i$ [s]	Evacuation scenario E_i [-]	Number of occupants exposed N_i [pers]
S01	F01	350	E01	0
S02	F01	350	E02	0
S03	F01	350	E03	0
S04	F01	350	E04	0
S05	F01	350	E05	0
S06	F02	265	E01	0
S07	F02	265	E02	1
S08	F02	265	E03	0
S09	F02	265	E04	1
S10	F02	265	E05	1
S11	F03	185	E01	4
S12	F03	185	E02	6
S13	F03	185	E03	12
S14	F03	185	E04	36
S15	F03	185	E05	61
S16	F04	175	E01	6
S17	F04	175	E02	9
S18	F04	175	E03	24
S19	F04	175	E04	48
S20	F04	175	E05	72
S21	F03	185	E06	26
S22	F03	185	E07	52
S23	F03	185	E08	78
S24	F03	185	E09	104
S25	F03	185	E10	130
S26	F04	175	E06	26
S27	F04	175	E07	52
S28	F04	175	E08	78
S29	F04	175	E09	104
S30	F04	175	E10	130

Table 12 – Case study, Network 1 – Likelihood of risk scenarios

Risk scenario **S_i** **[-]**	**Probability** **P_i** **[-]**	**Frequency** **F_i** **[year^{-1}]**
S01	7.99E-02	7.99E-06
S02	1.31E-01	1.31E-05
S03	2.54E-01	2.54E-05
S04	1.31E-01	1.31E-05
S05	1.31E-01	1.31E-05
S06	4.21E-03	4.21E-07
S07	6.89E-03	6.89E-07
S08	1.34E-02	1.34E-06
S09	6.89E-03	6.89E-07
S10	6.89E-03	6.89E-07
S11	1.41E-02	1.41E-06
S12	2.31E-02	2.31E-06
S13	4.49E-02	4.49E-06
S14	2.31E-02	2.31E-06
S15	2.31E-02	2.31E-06
S16	7.43E-04	7.43E-08
S17	1.22E-03	1.22E-07
S18	2.36E-03	2.36E-07
S19	1.22E-03	1.22E-07
S20	1.22E-03	1.22E-07
S21	1.05E-02	1.05E-06
S22	1.71E-02	1.71E-06
S23	3.33E-02	3.33E-06
S24	1.71E-02	1.71E-06
S25	1.71E-02	1.71E-06
S26	5.50E-04	5.50E-08
S27	9.00E-04	9.00E-08
S28	1.75E-03	1.75E-07
S29	9.00E-04	9.00E-08
S30	9.00E-04	9.00E-08
Total	1.00	1.00E-04

Table 13 – Case study, Network 1 – Consequences and frequency of risk scenarios

Consequences **N_i** **[pers]**	**Frequency** **F_i** **[year^{-1}]**	**Cumulative frequency** **ΣF_i** **[year^{-1}]**	**Risk scenario** **S_i** **[-]**
N > 130	0.00E+00	0.00E+00	-
104 < N ≤ 130	1.80E-06	1.80E-06	S25, S30
78 < N ≤ 104	1.80E-06	3.60E-06	S24, S29
70 < N ≤ 78	3.50E-06	7.10E-06	S23, S28
61 < N ≤ 70	1.22E-07	7.22E-06	S20
52 < N ≤ 61	2.31E-06	9.53E-06	S15
47 < N ≤ 52	1.80E-06	1.13E-05	S22, S27
34 < N ≤ 47	1.22E-07	1.15E-05	S19
26 < N ≤ 34	2.31E-06	1.38E-05	S14
21 < N ≤ 26	1.10E-06	1.49E-05	S21, S26
14 < N ≤ 21	2.36E-07	1.51E-05	S18
10 < N ≤ 14	4.49E-06	1.96E-05	S13
6 < N ≤ 10	1.22E-07	1.97E-05	S17
5 < N ≤ 6	2.38E-06	2.21E-05	S12, S16
1 < N ≤ 5	1.41E-06	2.35E-05	S11
0 < N ≤ 1	1.34E-06	2.48E-05	S08
N = 0	7.52E-05	1.00E-04	S01-07, S09, S10