# Benefits of sprinkler protection for personal safety of building occupants

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**Abstract**
Sprinkler protection limits the spread of fire but not necessarily the spread of smoke. Nevertheless, sprinkler protection might have a positive influence on evacuation safety because limiting fire development means also limiting smoke production. This study was carried out with CFAST (multizone simulations) for three different cases. All cases were simulated with and without sprinkler protection.

The assessment on personal safety of the building users depends on the definition of evacuation safety. In most building codes, safe evacuation is implicitly defined as reaching a safe area without health damage. This corresponds to a set of strict assessment criteria.
In small rooms, the sprinkler is activated too late to make a significant improvement in evacuation safety. However, sprinkler protection can be of value if instead of assessing the criteria for health, the criteria for lethality are assessed.

The conclusion is that sprinkler protection improves personal safety in a large compartment, based on an assessment on health criteria (evacuation concept). In small compartments and corridors connected to them, the improvement of personal safety by using sprinkler protection is negligible when assessing the health criteria. However, when assessing lethality criteria (life safety concept) sprinkler protection improves the personal safety of the building users.

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# Introduction

The main goal of this study is to determine whether or not sprinkler protection has any positive influence on evacuation safety. Sprinkler protection limits the spread of fire but not necessarily the propagation of smoke. Nevertheless, sprinkler protection might have a positive influence on evacuation safety because limiting fire development means also limiting smoke production. In hospital wards sprinkler protection is often used for this reason and measurements confirm the benefits of sprinkler protection (Hostikka et al, 2020).

This study was carried out for the European Fire Sprinkler Network (Van Herpen et al, 2018), based on CFAST multizone simulations for three different cases:

1. Evacuation safety in a large compartment with a stratified smoke layer
2. Evacuation safety in  a large compartment with smoke mixed in the compartment volume
3. Evacuation safety in a corridor and a small compartment connected to this corridor

All cases were simulated with and without  sprinkler protection. From that comparison, the following research question should be answered:
*What is the influence of sprinkler protection in the conditions in the fire room and the escape route, and what does that mean for personal safety of the building users?*

# Objective-based evacuation

In most building codes there are regulations regarding walking distances and evacuation routes (number, redundancy, capacity, finish, etc.). They are intended to enable building users to leave the building safely under fire conditions. This means that building users can evacuate the building to a safe area (mostly outside the building) without any health damage (or with a very low risk of health damage).

However, it is often possible to realize this objective differentlythan with public law requirements, by making use of project-specific characteristics. In a large compartment with a high ceiling, a local fire will result in a stratified situation, where the smoke is buffered in a hot zone in the upper part of the compartment, above of a relatively cold and clean zone underneath. As long as the escape routes are in the cold zone, building users can safely evacuate.

In a large compartment with a low ceiling, stratification does not occur. In this case, a mixed situation is assumed. Although the mixed situation is less favourable than the stratified situation, in amixed situation, there is also more evacuation time available in a large compartment because the volume of the large compartment makes the smoke more diluted than in a small compartment.

The available safe egress time (ASET) is in both the stratified and the mixed situation determined by the conditions (temperature, visibility, etc.) in the compartment. As long as the conditions in the compartment are acceptable for building users, safe evacuation is possible. When those conditions become so threatening that there is a high probability of health damage to the evacuating building users, the available safe egress time has been reached.

The required safe egress time (RSET) is the time needed for the building users to leave the endangered compartment or escape route. As long as the required time does not exceed the available time, building users can safely evacuate: RSET <ASET.

In such a project-specific, objective-based consideration of evacuation safety, both ASET and RSET contain a lot of uncertainty. As the interval (safety margin) between ASET and RSET decreases, the probability of failure (the chance that safe evacuation is not possible: RSET > ASET) increases. If ASET and RSET would not contain any uncertainty at all, a safety margin between ASET and RSET is superfluous. In practice, this is never the case.

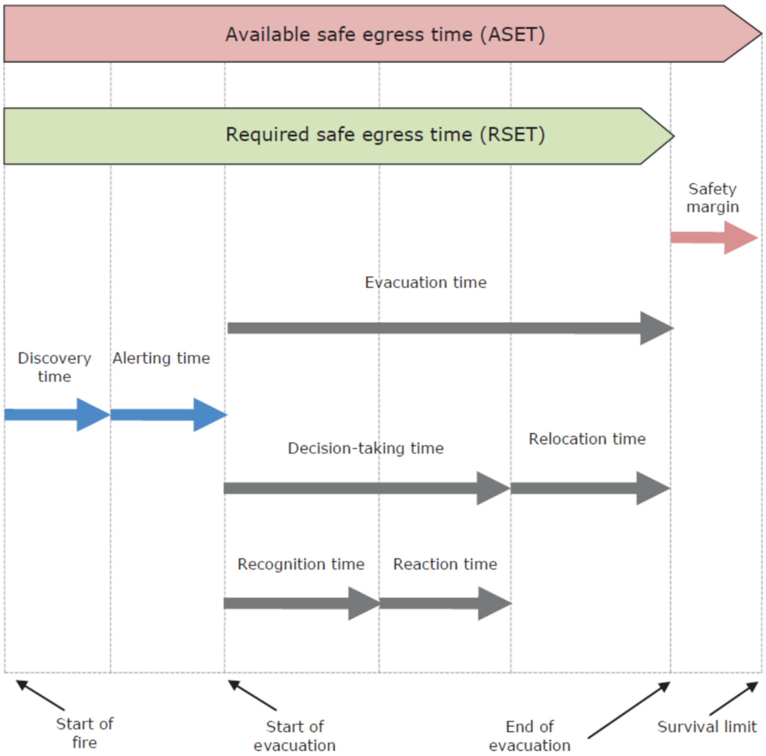



**Figure 1: Safe evacuation is possible if ASET > RSET. The safety margin is the difference between ASET and RSET (Hagen et al, 2017)**

Both ASET and RSET have uncertainty. Only the ASET can be influenced with a sprinkler protection. Therefore, only the influence of a sprinkler protection on the ASET is taken into account. This is done by comparing the ASET in the non-sprinklered reference situation with the ASET in the sprinklered situation.

## Assessment criteria for personal safety

The possibility of health damage to building users during the evacuation phase depends on the compartment conditions and the duration of exposure. With a duration of exposure of a few minutes, the following boundary conditions are used for limiting the health damage to the building users (derived from an exposure duration of a few minutes, from the Swedish Building Code, European Guideline 19, and ISO 13571).

In a stratified situation:

- The smoke-free height above the floor of the evacuation route is at least 2.5 meters

- The radiation flux from the smoke layer does not exceed 2.5 kW/m$^2$ at 1,8 meters above the floor of the evacuation route (head height); this corresponds to a radiation temperature of the smoke buffer of a maximum of 200 $^o$C.

In a mixed situation:

- The convective (gas) temperature does not exceed 70 $^o$C
- The visibility for light-reflecting objects is at least 5 meters.

To prevent health damage to building users strict assessment criteria are used, particularly in a mixed situation. The visibility requirement is decisive in this. Although poor visibility does not directly lead to health damage, building users can no longer orient themselves well. This has consequences for the RSET (longer required evacuation time). Due to the longer exposure time, the toxicity of the smoke can lead to health damage. With visibility lengths of more than 5 meters, the toxicity of the smoke is not significant.

In many countries, lethality is used as an assessment  criterion. When sprinkler protection refers to a 'life safety concept' is meant sprinkler protection with which the survival probability under fire conditions is increased. Health damage is then acceptable, as long as there are no fatalities. The lethality criterion is particularly useful in small rooms equipped with sprinkler protection. In those rooms, a mixed situation must be assumed.

For lethality as an assessment criterion, the CO pollution is the most important toxic component in a cellulosic fire. For the CO pollution, instead of a limit value, an acceptable dose has to be applied (ISO 13571). For the lethality criterion, the visibility requirement is therefore replaced by:

- Maximum CO-dose of 35.000 ppm.min;
- Minimal $O_2$-concentration of 60.000 ppm.

# Project specific boundary conditions

An objective-based assessment of the personal safety of building users is not possible with a standard fire according to the building code. A natural fire has to be applied, taking into account building characteristics and fire/fuel characteristics.

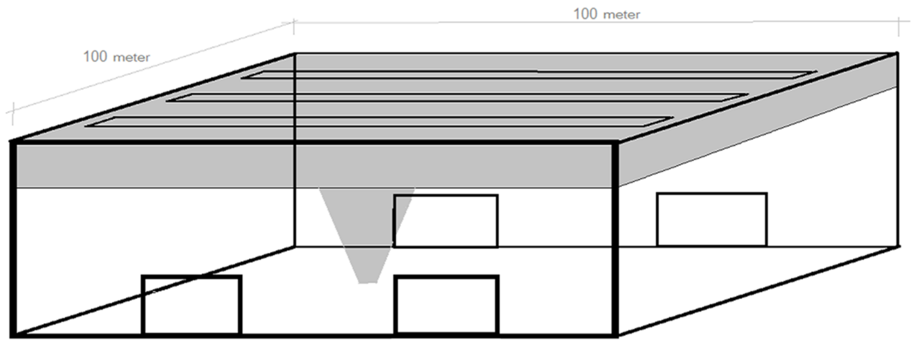
**Building characteristics**

In this study, three cases are considered in which the non-sprinklered reference situation is compared with a sprinklered situation:

1. Large compartment with a high ceiling (stratified situation) containing a commercial, meeting or industrial building-function
2. Large compartment with a low ceiling (mixed situation) containing a commercial, meeting or industrial building-function
3. Corridor connected with a small compartment (mixed situation) containing with a residential or accommodation building-function

The dimensions of the large compartment with a high ceiling are 100m x 100m (10000m$^2$) with an internal height of 7 meters. This compartment can contain a commercial function, meeting function or industrial function. The compartment, in this case, has four access doors of 3 x 3 m$^2$ each. The doors will be opened by the fire alarm. The compartment separation constructions are assumed to be adiabatic. That can be considered as the worst assumption.

Any daylight openings in the external separation constructions remain intact during the evacuation phase (pre-flashover).

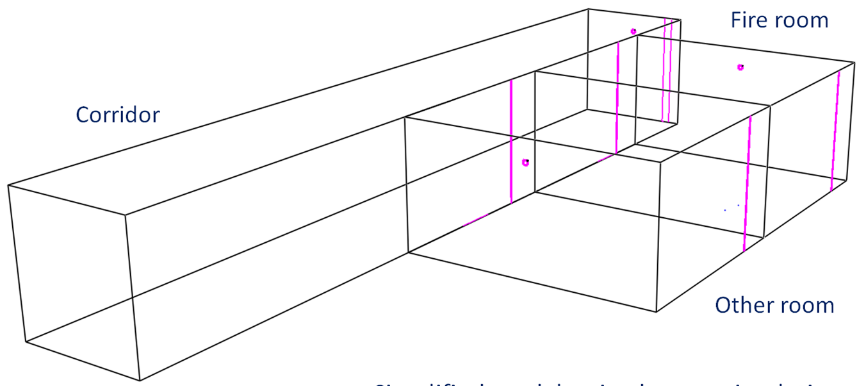



Simplified model, 2 zone simulation:
10,000 m² floor area
7 m height

**Figure 2: Large compartment with a high ceiling, stratified (2 zones) situation**

The large compartment with a low ceiling is comparable with the above described large compartment. The large compartment with a low ceiling only differs in the dimensions: 50 x 70 $m^2$ with an internal height of 4,5 meters.

In the corridor attached to small the compartments, one of these small compartments is assumed to be the fire room. This small room is 5m x 6m (30 $m^2$) and 3m high. It has one door to the corridor, including a gap underneath the door of 0.02 m. It is assumed that the external walls of the small compartments don't have any doors. Any daylight openings are closed and remain intact during the evacuation phase (pre-flashover). A leakage of 1% is assumed in both internal and external separation walls, in accordance with NEN 6055. External separation constructions never are completely airtight. All separation constructions are assumed to be adiabatic (worst case).




Simplified model, mixed zones simulation:
30 m² floor area (fire room)
3 m height

**Figure 3: Corridor attached to a small compartment, mixed zones in all compartments**

The normal use of (mechanical) ventilation is not significant for fire simulations. The ventilation capacities that are necessary for a healthy indoor climate, according to the Building Code, are so small that they do not affect the fire scenario. In this case, the air is mechanically supplied to the rooms (compartments) and mechanically extracted via the corridor.

**Fire / fuel characteristics**

In the compartments normal furniture and furnishings are assumed, the fuel is set up as cellulose. For a cellulose fuel, a generic molecular formula $C_4H_6O_3$ is used, with the following characteristics (NEN 6055, Quintière, 1997):

- Stoichiometric constant: r = 1,27 kg/kg
- Heat of combustion: Hc = 17,5 MJ/kg
- Uniformly distributed variable fire load: 1050 MJ/$m^2$ (assumption, not relevant)
- T-squared heat release rate curve with a time constant: $t_c$ = 150 s (fast)
- Heat release rate per unit area: RHRPUA= 500 kW/$m^2$ for large compartments,
  RHRPUA= 250 kW/$m^2$ for small compartments
- Plume model (only in the stratified situation): Heskestad
- Fire height (only in the stratified situation): 1 meter
- Mass optical density (only in a mixed situation): 100 $m^2$/kg
- Soot yield (only in a mixed situation): 2,6 %
- CO-yield (only in a mixed situation): 1,0 %

In case of activation of the sprinkler protection, the sprinkler influences the heat release rate and the composition of the smoke. A conservative modelling of the sprinkler protection is determined by its activation and is based on the Detact algorithm (Evans, Stroup). After activation, the heat release rate remains constant. Of course, the sprinkler protection will reduce the heat release rate density, which means that with a constant heat release rate the fire area (and thus the perimeter of the plume) increases. It is assumed that after sprinkler activation, the heat release rate is halved and the fire area is doubled. This increases the perimeter of the plume and the entrainment of ambient air.

This method of sprinkler modelling is simple and robust. The following sprinkler characteristics are used in case of sprinkler protection:

- Grid of the sprinklers heads: 3 x 3 m in large compartments, 4 x 3 m in small compartments
- Activation temperature: 68 $^oC$ in both large and small compartments
- Response Time Index: RTI = 50 $(m.s)^{0,5}$ in large compartments,
  RTI = 35 $(m.s)^{0,5}$ in small compartments (quick response)
- Soot yield (after sprinkler activation): 5,2 %
- CO yield (after sprinkler activation): 10,0 %

The soot yield and CO yield increase after the sprinkler activation because the sprinkled fire is not only cooled but is also partly smothered. This causes incomplete combustion. Figure 4 illustrates the consequences for the soot yield and the CO yield in case of a smothering fire (Quintiere, 1997).

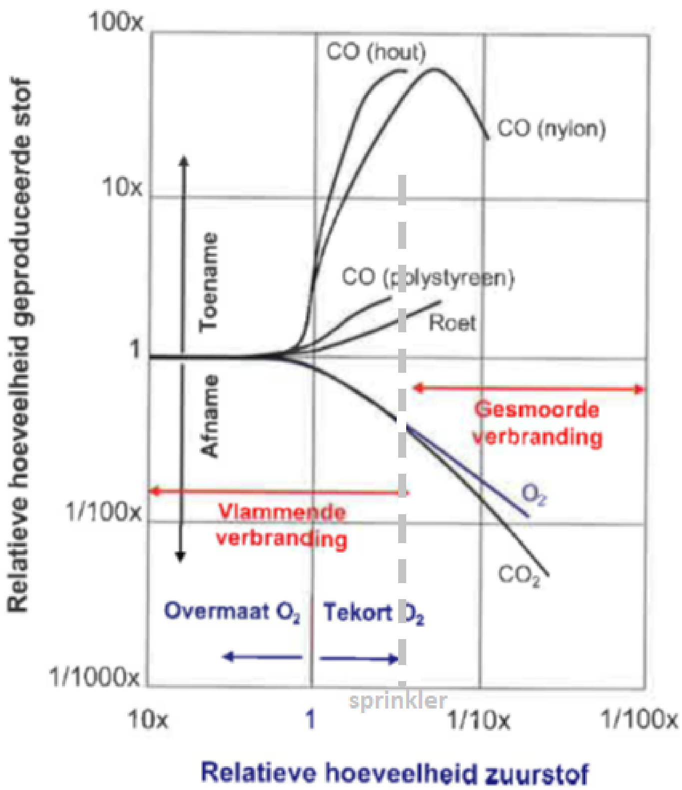



**Figure 4: Production of soot and CO, depending of the degree of smothering. The dashed grey line indicates the local smothering of the sprinkler, whereby the soot yield is increased by a factor 2 and the CO yield by a factor of 10 (Quintière, 1998).**

For the mixed situation in small compartments (as is present in the corridor-case), the above described sprinkler modelling appears to be too simple. As a result, the sprinkler system is activated much later than it is activated in reality (Williams et al, 2005). The activation is even so late that the sprinkler protection is not important for the personal safety of the building users. In the first place, the late activation is due to the quadratic modelling of the heat release rate. This is not realistic for small compartments. In the second place, the late activation is due to the neglect of the influence of separation constructions of small compartments, which leads to higher temperatures at the sprinkler heads.

In reality, there is indeed a difference between the non-sprinklered reference situation and the sprinklered situation, especially when personal safety is defined based on lethality instead of health damage.

A more detailed definition of sprinkler protection is necessary to overcome the above-mentioned shortcomings. This means that more sprinkler characteristics are relevant, which makes the modelling more complex and less robust, but a better fit to reality. For this more detailed modelling of the sprinkler protection in small compartments, the following characteristics are added:

- Spray density: 2,25 mm/min in small compartments
- Reduction of the heat release rate density after sprinkler activation

The reduction of the heat release rate after sprinkler activation is given by the following equation (Wade et al., 2004, 2007):

$$RHR(t) = RHR(t_{act}) * e^{-\frac{t-t_{act}}{3*u_w^{-1,8}}}$$

Where:

- $t$ time
- $t_{act}$ sprinkler activation time
- $u_w$ spray density

Instead of a constant heat release rate after sprinkler activation, the heat release rate decreases. This is possible because the spray density is known. Another spray density leads to a different decrease of the heat release rate.

## Stochastic boundary conditions

The ASET is determined by assessing the conditions in the compartment, based on a natural fire scenario, on the acceptable conditions. However, this assessment is not deterministic, since the boundary conditions are uncertain. This applies in particular to the fire (fuel) conditions.

The most important stochastic boundary conditions in the stratified situation are:

- Heat release rate density
- Time constant for fire development
- Fire height
- Heat of combustion

In the mixed situation the most important stochastic boundary conditions are:

- Heat release rate density
- Time constant for fire development
- Heat of combustion
- Soot yield
- CO yield

For the small compartments connected with the corridor access, the following stochastic building characteristics have to be added, which also have to do with the escape behaviour of the building users:

- Time of opening access door
- Duration of access door opened

First, fire simulations for the determination of the ASET are performed in all cases, with the building characteristics and fuel characteristics previously mentioned. Then a sensitivity analysis is performed, where each stochastic parameter ($x_i$) is individually varied with its (estimated) standard deviation ($dx_i = s_i$). This results in a variation of the ASET (dt).

The specific variation per stochastic parameter of the ASET is defined as $dt/dx_i$, which leads to a specific variance in the ASET of $(s_i \cdot dt/dx_i)^2$. Each stochastic parameter has its own

specific variance in the ASET. The summation of all specific variances gives the total variance of the ASET:
$var_{ASET} = \Sigma_i (s_i \cdot dt/dx_i)^2$.
The standard deviation of the ASET ($s_{ASET}$) is the square root of the variance:
$s_{ASET} = \sqrt{(var_{ASET})}$.

The probability distribution function of each individual stochastic parameter is not known but the standard deviation can be determined or estimated relatively easily. When in the determination of the ASET a large number of stochastic parameters are involved, the ASET will be approximately normally distributed on the basis of the central limit theorem in the probability theory.

By performing the sensitivity analysis as described above, the probability distribution function of the ASET can be reliably determined. A Monte-Carlo analysis is not necessary and even does not make sense, because the probability distribution functions of the individual stochastic parameter are not known.

The technique described here for performing a quantitative sensitivity analysis has previously been applied in the research carried out at the request of the NEN (Netherlands Normalization Institute) for the reliability of load-bearing elements in case of fire (Van Herpen et al., 2014).

For each stochastic boundary condition ($x_i$):

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

For ASET ($t$):

| | |
|---|---|
| Variation: | $dt$ |
| Specific Variation per stochast: | $dt/dxi$ |
| Specific Variancy per stochast: | $(s_i\ dt/dxi)^2$ |
| Total Variancy: | $var = \sum_i (s_i\ dt/dxi)^2$ |
| Standard Deviation: | $s = \sqrt{var}$ |

**Figure 5: Summary of the methodology for quantitative sensitivity analysis**

# Simulation results and sensitivity analysis

The simulations are performed with the multizone model CFAST (NIST, version 7.2.3, 2017). In CFAST it is possible to model several rooms connected to each other, with a closed-door or a partially open door. Both a stratified (2 zones) and a mixed (1 zone) situation can be simulated in CFAST.

Air leakages, building characteristics, and fuel/fire characteristics are taken into account in the CFAST models.

In the large compartments, the Detact algorithm is used for the determination of the sprinkler activation time. In the small room, the algorithm of Wade is used for the determination of sprinkler activation and the sprinklered RHR-scenario.

**Large compartment with a high ceiling**

In a large compartment with a high ceiling, a stratified (2-zones) situation is assumed in case of a developing local fire. In the situation, without sprinkler protection, the smoke free height is the significant criterion as 22 minutes after fire starts the smoke free height becomes insufficient. With sprinkler protection, the smoke free height is sufficient during the total fire scenario.

**Table 1. Deterministic assessment of ASET in the large compartment with high ceiling**

| **Large compartment**<br>**Stratified situation** | **ASET [min]**<br>**No sprinkler** | **ASET [min]**<br>**Sprinkler** |
|---|---|---|
| Criterion smoke free height | 22 | > 60 |
| Criterion smoke layer temperature | 25 | > 60 |

Because of the stochastic boundary conditions, a sensitivity analysis is performed. An overview of stochastic boundary conditions is given in table 2.

**Table 2. Overview of stochastic boundary conditions**

| **Parameter** | **Average**<br><br>**AVG** | **Variation coefficient**<br>**V** | **Standard deviation**<br>**SD = V x AVG** |
|---|---|---|---|
| Heat release rate density [kW/m$^2$] | 500 | +0.5<br>-0.3 | +250<br>-150 |
| Time constant for fire spread [s] | 150 | +0.5<br>-0.3 | +75<br>-45 |
| Heat of combustion [MJ/kg] | 17.5 | +0.1<br>-0.1 | +1.75<br>-1.75 |
| Fire height [m] | 1 | +1.0<br>-1.0 | +1.0<br>-1.0 |

The results of the sensitivity analysis are in the non-sprinklered situation an average value of ASET = 23 min, with a standard deviation of SD = -8.9 min and SD = +16.7 min. In the sprinklered situation the average value of ASET > 60 min, the standard deviation couldn’t be determined.

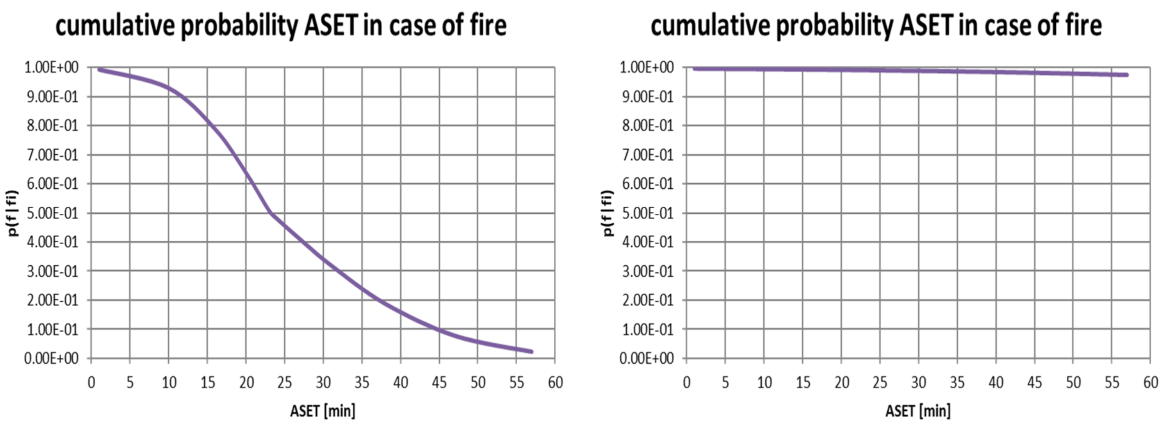



**Figure 6: Cumulative probability distribution ASET in the large compartment with high ceiling, criterion smoke free height > 2,5 m (left: non-sprinklered reference situation; right: sprinklered situation)**

## Large compartment with a low ceiling

In a large compartment with a low ceiling, a mixed (1-zone) situation is assumed in case of a developing local fire. In the situation without sprinkler protection, the visibility is the significant criterion as 6 minutes after fire starts the visibility becomes insufficient. With sprinkler protection, visibility becomes insufficient after 9.5 minutes.

**Table 3. Deterministic assessment of ASET in the large compartment with low ceiling**

| **Large compartment<br>Mixed situation** | **ASET [min]<br>No sprinkler** | **ASET [min]<br>Sprinkler** |
|---|---|---|
| Criterion visibility | 6 | 9.5 |
| Criterion gas temperature | 13.5 | > 60 |

Because of the stochastic boundary conditions a sensitivity analysis is performed. An overview of stochastic boundary conditions is given in table 4.

**Table 4. Overview of stochastic boundary conditions**

| **Parameter** | **Average<br><br>AVG** | **Variation coefficient<br>V** | **Standard deviation<br>SD = V x AVG** |
|---|---|---|---|
| Heat release rate density [kW/m$^2$] | 500 | +0.5<br>-0.3 | +250<br>-150 |
| Time constant for fire spread [s] | 150 | +0.5<br>-0.3 | +75<br>-45 |
| Heat of combustion [MJ/kg] | 17.5 | +0.1<br>-0.1 | +1.75<br>-1.75 |
| Soot yield [%] | 2.6<br>(no sprinkler)<br>5.2<br>(sprinkler) | +0.5<br>-0.5<br>+0.5<br>-0.5 | +1.3<br>-1.3<br>+2.6<br>-2.6 |
| CO yield [%] | 1.0<br>(no sprinkler)<br>10.0<br>(sprinkler) | +0.5<br>-0.5<br>+0.5<br>-0.5 | +0.5<br>-0.5<br>+5.0<br>-5.0 |

The results of the sensitivity analysis are in the non-sprinklered situation an average value of ASET = 6.2 min, with a standard deviation of SD = -1.7 min and SD = +2.5 min. In the sprinklered situation the average value of ASET = 9.5 min, with a standard deviation of SD = -1.3 min and SD = + 2.5 min.

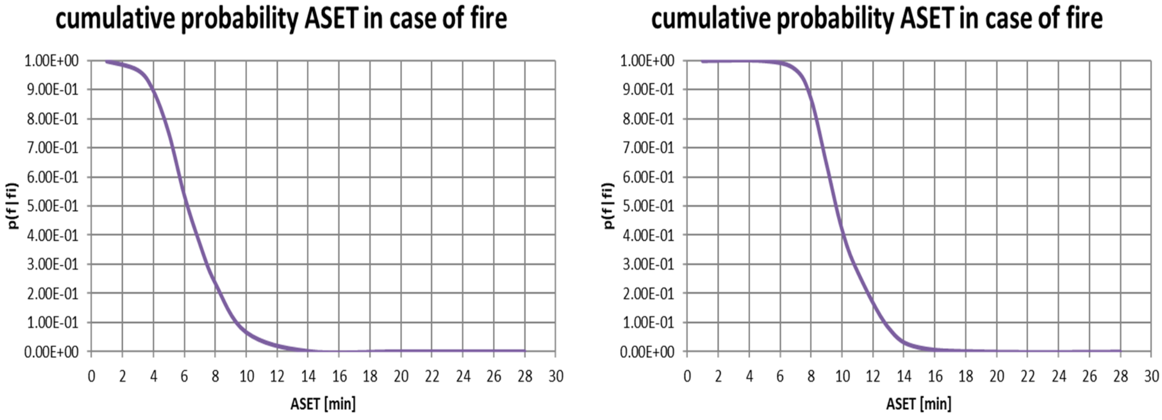



**Figure 7: Cumulative probability distribution ASET in the large compartment with low ceiling, criterion visibility > 5 m (left: non-sprinklered reference situation; right: sprinklered situation)**

### Small compartment attached to a corridor

In a small compartment, a mixed (1-zone) situation is assumed in case of a developing local fire. This mixed situation is also present in the corridor connected to this compartment. In the situation without sprinkler protection, visibility is the significant criterion in the corridor (the escape route) as 5 minutes after the fire starts the visibility becomes insufficient due to opening the door of the fire compartment. With sprinkler protection, the visibility in the corridor becomes insufficient after 5.5 minutes.

**Table 5. Deterministic assessment of ASET in the corridor, connected to a small compartment**

| **Corridor**<br>**Mixed situation** | **ASET [min]**<br>**No sprinkler** | **ASET [min]**<br>**Sprinkler** |
|---|---|---|
| Criterion visibility | 6 | 9.5 |
| Criterion gas temperature | 13.5 | > 60 |

Because of the stochastic boundary conditions a sensitivity analysis is performed. An overview of stochastic boundary conditions is given in table 6.

**Table 6. Overview of stochastic boundary conditions**

| Parameter | Average<br>AVG | Variation coefficient<br>V | Standard deviation<br>SD = V x AVG |
|---|---|---|---|
| Heat release rate density [$kW/m^2$] | 250 | +0.5<br>-0.3 | +250<br>-150 |
| Time constant for fire spread [s] | 150 | +0.5<br>-0.3 | +75<br>-45 |
| Heat of combustion [MJ/kg] | 17.5 | +0.1<br>-0.1 | +1.75<br>-1.75 |
| Soot yield [%] | 2.6<br>(no sprinkler)<br>5.2<br>(sprinkler) | +0.5<br>-0.5<br>+0.5<br>-0.5 | +1.3<br>-1.3<br>+2.6<br>-2.6 |
| CO yield [%] | 1.0<br>(no sprinkler)<br>10.0<br>(sprinkler) | +0.5<br>-0.5<br>+0.5<br>-0.5 | +0.5<br>-0.5<br>+5.0<br>-5.0 |
| Time door open [min] | 5 | +0.4<br>-0.4 | +2.0<br>-2.0 |
| Duration door open [min] | 1 | +0.5<br>-0.5 | +0.5<br>-0.5 |

The results of the sensitivity analysis are in the non-sprinklered situation an average value of ASET = 5.1 min, with a standard deviation of SD = -2.0 min and SD = +1.9 min. In the sprinklered situation the average value of ASET = 5.4 min, with a standard deviation of SD = -1.6 min and SD = + 2.1 min.

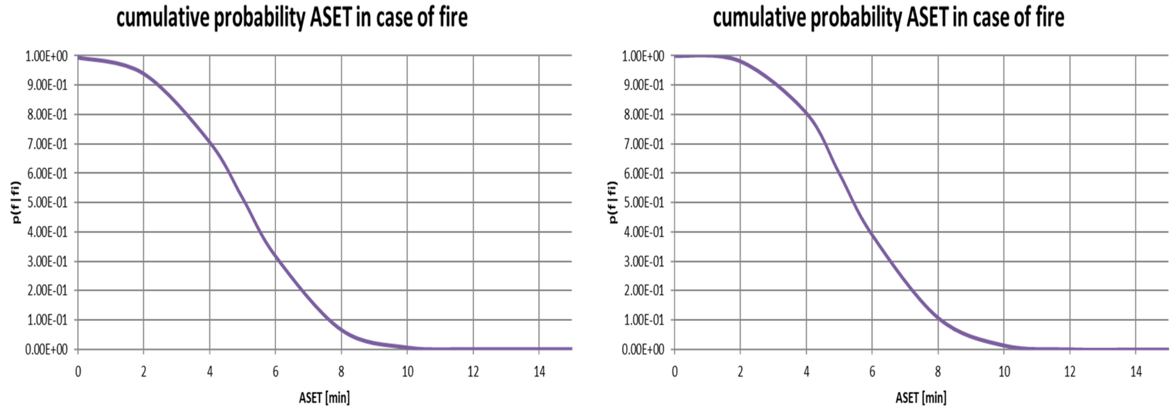



**Figure 8: Cumulative probability distribution ASET in the corridor, criterion visibility (left: non-sprinklered reference situation; right: sprinklered situation)**

Figure 8 shows that there is hardly any difference between the non-sprinklered and sprinklered situation. Eliminating the time that the door opens gives a slightly better result, but still, the ASET in the corridor is very short in both the non-sprinklered and the sprinklered situation, see figure 9.

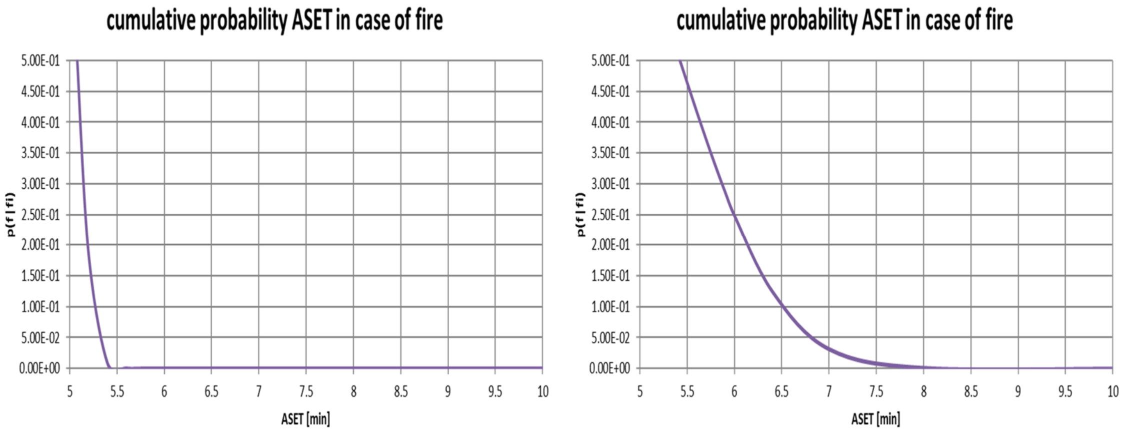



**Figure 9: Cumulative probability distribution ASET in the corridor, criterion visibility, after opening the door of the fire compartment (5 minutes)**
**(left: non-sprinklered reference situation; right: sprinklered situation)**

In small compartments, the influence of sprinkler protection seems to be very small when the ASET is assessed on visibility in the corridor (the escape route). However, when the ASET is assessed on the carbon monoxide dose (lethality), the influence of sprinkler protection is obvious, in both the corridor (figure 10) and the small compartment (figure 11).

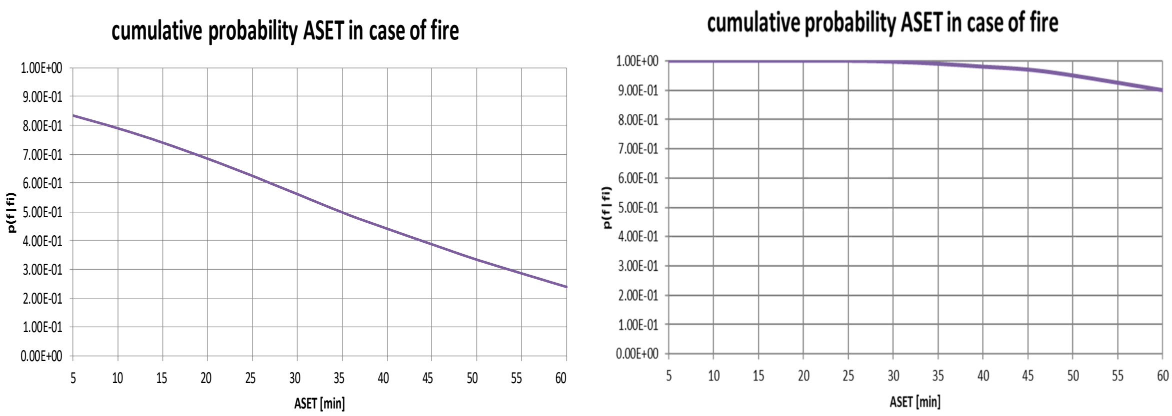



**Figure 10: Cumulative probability distribution ASET in the corridor, criterion CO-dose, after opening of the fire compartment (5 minutes)**
**(Left: non-sprinklered reference situation; Right: sprinklered situation)**

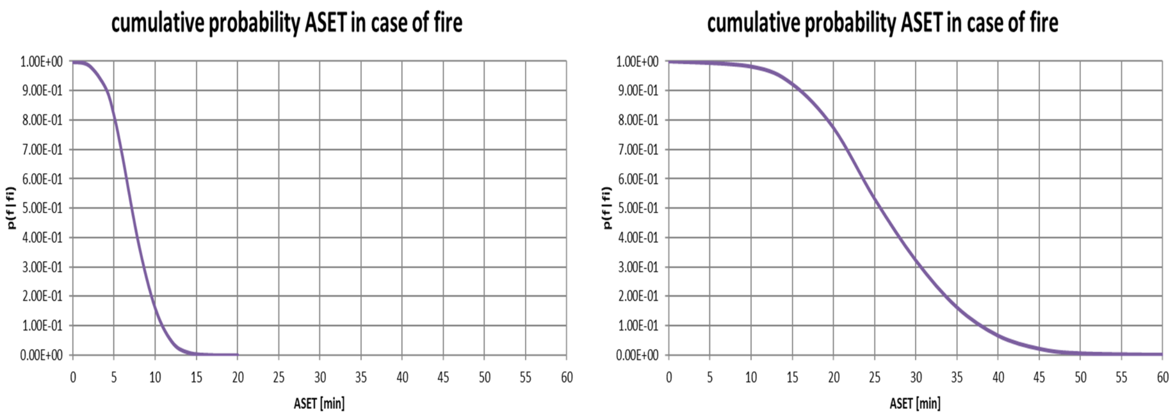



**Figure 11: Cumulative probability distribution ASET in the fire compartment, criterion CO-dose (Left: non-sprinklered reference situation; Right: sprinklered situation)**

# Evaluation

For the three cases in this study, the evacuation conditions are simulated using a multizone model for both, a reference situation without sprinkler protection, and a situation with sprinkler protection. The following conclusion can be drawn from this comparison, in answer to the research question:

*In all cases, a sprinkler protection slows the deterioration of the conditions for the building users and therefore has a positive impact on the personal safety.*

More nuanced, for the health damage criterion can be concluded:

- In a large compartment in which a stratified situation occurs in the event of a fire, the sprinkler protection guarantees the personal safety of building users throughout the fire scenario. Thanks to the sprinkler protection, there is no time pressure on the evacuation of building users. In a stratified situation, the smoke is buffered in the hot zone in the upper part of the compartment, above of relatively cold and clean zone below.
- In a large compartment in which a mixed situation occurs, in the event of a fire, the available safe egress time (ASET) is increased by a factor of 1.6 (with a 50% reliability of ASET) to 2.2 (with a 95% reliability of ASET) when comparing the sprinkler situation with the non-sprinklered reference situation. However, in the sprinklered situation, the evacuation time remains limited and there is time pressure on the evacuation of building users.
- In the corridor connected to small compartments, the visibility, in both the fire compartment and the corridor with sprinkler protection, decreases less quickly than in the non-sprinklered reference situation, but the available safe egress time (ASET) is very short in both cases.

The above conclusion concerning the corridor, connected to small compartments, goes against the prevailing view (Williams et al., 2005, Wieczorek et al., 2010). The reason for this lies in the assessment criterion. The criterion for preventing health damage (‘evacuation safety’) is strict.

Some health damage is usually accepted. It is only in the case of serious health damage that social boundaries are reached. Lethality is the most serious form of health damage. Survival is therefore a social condition. This is often addressed as a ‘life safety concept’.

When the lethality criterion is applied, for sprinkler protection of small compartments attached to a corridor can be concluded:

- In case of fire, the available safe time (AST ) in the fire compartment with sprinkler protection is multiplied by a factor of 3.6 (with 50% reliability of AST) to 4.5 (with 95% reliability of AST) compared to the non-sprinklered reference situation.
- The available safe time (AST ) in the corridor attached to a sprinkler protected small compartment is longer than the fire duration. Therefore, the AST in the corridor is theoretically infinitely.

It should also be noted that the conclusions drawn here are only valid for the cases simulated in this study. The expectation is that extrapolation of the conclusions is possible within reasonable limits.

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NB:
NEN-, EN- en ISO standards are left outside this overview of the references. If references are made to NEN, EN and ISO standards, means that the most recently issued version was used, included any associated amendment.