

# The Effects of Cold Temperatures-When Pressurizing Firefighter Elevators

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**Abstract.** Pressurization systems are commonly used to protect firefighter elevator shafts from smoke ingress during fire incidents in high-rise buildings. In cold climates, however, these systems may introduce cold outdoor air into the elevator shaft, potentially lowering the shaft temperature below the operational limits of elevator components. Components for firefighter elevators are typically tested for operation only within a temperature range of approximately 0–40 °C or 0–65 °C according to current standards. Operation below freezing temperatures may therefore create uncertainty regarding the reliability of safety-critical components. This paper investigates the interaction between elevator shaft pressurization systems and low outdoor temperatures in Nordic climates. The study combines literature review, expert interviews, temperature measurements in buildings and quantitative risk analysis. Several mitigation strategies are evaluated, including heated supply air, indoor air routing, reduced airflow rates and temperature monitoring with automatic system control. Results show that shaft temperatures are often higher than outdoor temperatures due to heat transfer from the building structure, but that freezing conditions may still occur under certain scenarios. A temperature-based control strategy that temporarily deactivates pressurization when the shaft temperature drops below 0 °C is identified as a robust baseline safety measure. The findings contribute to the development of design guidelines for pressurized firefighter elevator systems in cold climates.

## 1 Introduction

Firefighter elevators are an important safety feature in modern high-rise buildings. Their primary function is to enable firefighters to quickly reach upper floors with personnel and equipment during emergency operations. Without such elevators, firefighters may be forced to climb many flights of stairs when operating in a building, which can significantly delay response time and increase physical fatigue. Consequently, building regulations in many countries require firefighter elevators in tall buildings. To ensure that firefighter elevators remain operational during a fire event, they must be protected from smoke infiltration. Smoke entering the elevator shaft can spread rapidly through the building and may impair the safe use of the elevator during rescue operations. One commonly used strategy for protecting the

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shaft from smoke is pressurization of the elevator shaft. In a pressurized shaft system, fans supply air to the shaft so that the pressure in the elevator shaft remains higher than that of surrounding spaces. The resulting pressure difference prevents smoke from entering the shaft through door gaps or other openings. Pressurization systems for smoke control have been widely studied in the context of stairwells and elevator shafts [4].

Although pressurization systems are widely used and generally regarded as effective, their implementation can create challenges in cold climates. In many design solutions, the air used for pressurization is taken from outdoor environments and during the winter in northern Europe this means that the temperatures for used for pressurization may be below freezing. If such cold air is supplied directly into the elevator shaft, it can significantly reduce the shaft temperature.

Elevator systems are typically tested and certified only within a defined temperature range. For firefighter elevators according to European standard, EN 81-72, this means that elevators are tested down to temperatures of 0 °C at the lowest. Operation below this temperature has not been extensively studied and at such temperatures, both electronic and mechanical components may be affected negatively. As a result, designers and authorities approving different design solutions face uncertainty when evaluating pressurized firefighter elevator systems in cold climates. This paper investigates the potential risks associated with low temperatures in pressurized firefighter elevator shafts and evaluates strategies to mitigate these risks [1].

## **2 Methodology**

The research presented in this paper is based on the findings in a Swedish report [1] where a combination of quantitative and analytical methods was used. The project has mainly been carried out in three parts: (1) identification of the problem, (2) identification of possible solutions, and (3) evaluation of possible solutions. Each of these stages is described in more detail below.

### **2.1 Experimental investigation**

To identify the issues associated with pressurizing firefighter elevators with cold air, interviews were conducted with fire safety consultants, manufacturers, suppliers, and inspectors. The aim of the interviews was to identify the problem, determine which parts of the elevator construction are particularly sensitive to cold, and to discuss/identify possible solutions to the issue together with those who possess the greatest technical expertise regarding the elevator's design. In addition to the above, actual temperature measurements have been carried out in firefighter elevator shafts that are already in operation. This was done to study the extent of the temperature impact in the elevator shaft when it is pressurized with cold air.

### **2.2 Interviews with Fire Safety Consultants**

Interviews with several fire safety consultants were conducted in June–July 2024 regarding the management of low temperatures in firefighter elevators. The consultants had extensive experience designing buildings with pressurized firefighter elevators. The main issue identified is that both electronic and mechanical elevator components are often not approved for low temperatures according to existing standards and test methods. It is unclear whether

these components have been tested at lower temperatures. The challenge is largely related to responsibility—specifically who can approve or take responsibility for alternative solutions where low temperatures may occur. At the same time, the components may function at low temperatures but lack formal testing.

None of the interviewed consultants had tested pressurization systems at low outdoor temperatures. Practical solutions used in projects include preheating the inlet air, typically to about +5 °C, which also reduces condensation risks. Because pressurization systems often require high airflow (5–10 m<sup>3</sup>/s), energy-efficient heating solutions such as district heating may be preferable to direct electric heating. Another option discussed was using preheated air from other parts of the building, such as garages, although this introduces risks if smoke is drawn into the system for certain failure scenarios. Additional measures may include heat sources such as heating cables. It is also likely that the elevator equipment itself generates heat, meaning shaft temperatures may be higher than the outdoor air temperature.

A common approach is to stop the pressurization system if temperatures in the shaft become too low. In such cases, the stack effect may still provide some smoke ventilation through openings at the top of the shaft and air supply at the bottom. Furthermore, during the interviews it was noted that elevators designed for outdoor environments may provide useful knowledge regarding components and design solutions for future firefighter elevators.

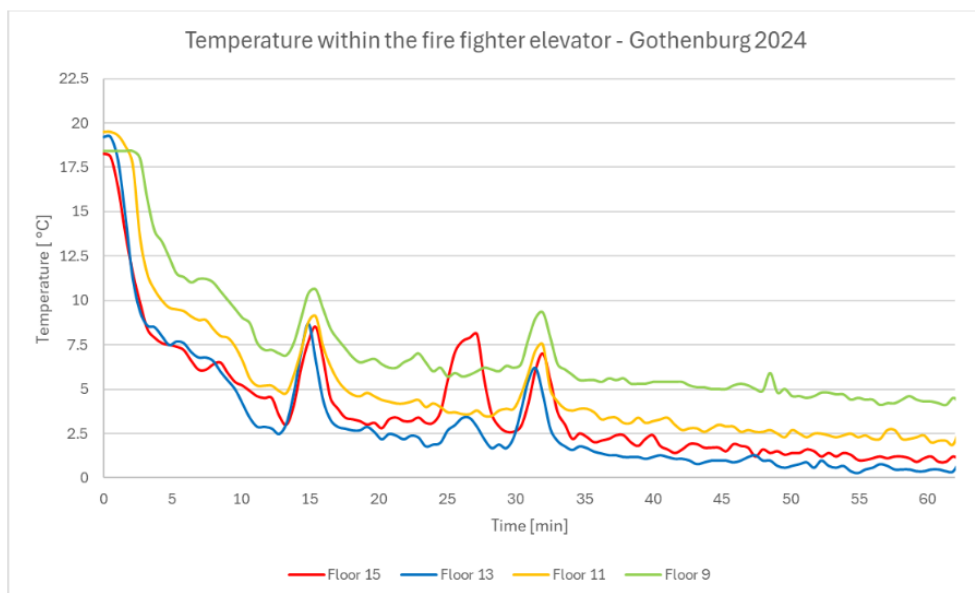
### **2.3 Interviews with Manufacturers, Suppliers and Inspectors**

Interviews were conducted with representatives from Kone, Kiwa, and Schindler. Cold temperatures in elevator shafts were identified as a potential issue since firefighter elevators are tested according to SS-EN 81-72 [2], which means within the temperature range of 0 to 40/65 °C. As a result, their performance at sub-zero temperatures is uncertain. Rapid temperature changes during pressurization may also cause condensation that can freeze and affect mechanical components or oils, although electronics are generally less sensitive due to heat generation. Common mitigation measures that the manufacturers have seen in real projects include thermostats that shut off fans, preheating the air, internal duct routing, or activating the system only when needed. Outdoor elevators handle cold conditions better through additional measures such as shaft heaters and heated enclosures for electronics, but these solutions are significantly more expensive.

Manufacturers typically adhere to their certifications, but alternative solutions may be accepted if verified and inspected properly. None of the interviewees were aware of any firefighter elevators failing due to low temperatures.

### **2.4 Temperature Measurements During Pressurization**

To investigate the actual temperatures that occur in firefighter elevator shafts during pressurization, four tests were conducted in installed systems—two in Gothenburg and two in Stockholm. Two systems supplied air from the top of the shaft with minimal ducting. The other two systems supplied air from the bottom, where some heating occurred through indoor ductwork. The results from one such measurement, that was performed in Gothenburg with an outside temperature of -11 °C is shown in Fig. 1. The pressurization system was designed with a roof fan on the elevator shaft, meaning that the fan injected outside air directly into the elevator shaft from the top. The pressurization was on for approximately one hour, with two short stops, which can be seen in the temperature “spikes” in the results.



**Fig. 1.** Results of temperature measurements in an elevator shaft during pressurization with an outside temperature of -11 °C.

Results showed that the temperature inside the shafts decreased when pressurization started but remained significantly higher than the outdoor temperature. The largest temperature drops generally occurred during the first 10 minutes, after which the decrease slowed considerably.

Standard design calculations for pressurization systems often assume conservative conditions where outdoor air temperature equals the supply air temperature. The measurements indicate that the supply air is heated by the fan, ductwork and the thermal mass of the shaft walls. Measurements also showed smaller temperature differences within the shaft than predicted by calculation models, resulting in a more uniform pressure profile. Overall, the measurements demonstrate a significant thermal inertia in both the system and the shaft structure, creating a noticeable temperature difference between outdoor air and the shaft environment. The results suggest that outdoor temperatures significantly below 0 °C and/or high airflow rates as well as long pressurization times would likely be required to reach sub-zero temperatures in the elevator shaft.

## 2.5 Conclusions Related to the Identified Problem

Firefighter elevators are tested for temperatures between 0 and 40/65 °C according to SS-EN 81-72. Outside this range, manufacturers do not guarantee the elevator's functionality. This creates uncertainty about how elevators would perform if sub-zero temperatures occurred in the shaft. Interviews with inspectors and manufacturers confirmed this uncertainty. Most consider it likely that the elevator and its safety functions would continue to operate at occasional sub-zero temperatures, but since such conditions are not tested, this cannot be confirmed with certainty.

Temperature measurements during pressurization at different outdoor temperatures show a clear difference between outdoor temperature and the temperature inside the shaft. This

difference increases as the outdoor temperature decreases and as the shaft temperature approaches 0 °C. Air is warmed by system components such as ducts and fans, and by the thermal inertia of the concrete shaft walls, resulting in higher shaft temperatures than outdoors. The measurements also show that the largest temperature drop occurs during the first 10 minutes of pressurization, after which the decrease becomes much smaller.

Temperature data from SMHI (Swedish Meteorological and Hydrological Institute) show significant regional variation in Sweden. In southern Sweden, about 10 % of recorded temperatures between 2008–2024 were below 0 °C, while in the far north nearly 40 % were below 0 °C during the same period. The measurements above, with an outdoor temperature of –11 °C, showed that the shaft temperature remained above 0 °C even after prolonged pressurization. Since this temperature corresponds to the 99th percentile of the yearly temperatures in southern Sweden, the risk of sub-zero temperatures occurring in the shaft during pressurization is considered unlikely in this part of the country, even for less favorable pressurization system designs. However, for northern Sweden, the risk of cold temperatures during pressurization is more prominent and needs further assessment.

### **3 IDENTIFICATION OF POSSIBLE SOLUTIONS**

Interviews with fire safety consultants, inspectors, and suppliers identified several potential solutions for managing risks related to low temperatures in firefighter elevator shafts. Additional solutions were discussed within the research group. A brief overview of the most relevant approaches is presented below. Since cold air may affect elevator functionality, any solution must include a safeguard that shuts down the pressurization system if the shaft temperature becomes too low. It is therefore proposed that a temperature sensor be installed in the shaft to stop the pressurization fan if the temperature remains below 0 °C for more than 60 seconds. The sensor should be located approximately two floors above the air supply, where the lowest temperatures are expected. This measure is recommended regardless of the selected solution, since elevator functionality cannot be guaranteed at sub-zero temperatures.

As the pressurization system may need to be shut down at low temperatures, the reliability of the system is affected and the risk of smoke entering the shaft may increase. Possible solutions can therefore be divided into two categories. (1) systems that prevent the shaft from becoming too cold, and (2) systems that reduce the risk of smoke entering the shaft.

Several strategies can be used to maintain temperatures above 0 °C in the shaft.

#### ***3.1.1 Heating of supply air.***

The incoming air can be heated before entering the shaft, for example using heating coils or the building's heating system (e.g., district heating). Based on interview experience, supply air is typically heated to around +5 °C at the design outdoor temperature. The system requires temperature control and depends on the proper function of sensors and heating equipment.

#### ***3.1.2 Heating through duct systems.***

If outdoor air passes through indoor ducts before reaching the shaft, it is passively warmed by heat transfer from the building. This is a simpler but less effective form of heating compared to active heating systems.

### *3.1.3 Using air from indoor spaces.*

Another option is to supply air from a tempered indoor environment, such as a garage. However, this introduces a new risk: if the system activates during a fire in that space, smoke could be spread throughout the building. Due to this risk, the option was not considered suitable for further evaluation.

### *3.1.4 Reduced fan capacity at low temperatures.*

Fan capacity could be reduced when shaft temperatures drop, allowing the thermal inertia of the concrete shaft to raise the temperature again. However, the system must still maintain a sufficient difference to prevent smoke spread, which may result in a lower safety margin.

### *3.1.5 Push–pull systems.*

Another approach is to combine the pressurization fan in the firefighter elevator shaft with an extraction fan in a nearby shaft (e.g., a passenger elevator shaft). This can maintain a small overpressure even if the main fan must be shut down due to low temperatures. The system relies on pressure control and proper system design.

### *3.1.6 Systems to Reduce the Risk of Smoke Spread – Sprinkler systems*

In addition to preventing low temperatures, other measures can reduce the risk of smoke entering the shaft. Sprinklers reduce the likelihood of large fires and therefore also reduce the risk of smoke spreading into the elevator shaft.

### *3.1.7 Systems to Reduce the Risk of Smoke Spread – Additional fire compartments*

Introducing additional fire separations—such as extra lobbies—between building areas and the shaft can also reduce the risk of smoke entering the firefighter elevator shaft, since multiple barriers increase the probability that at least one remains intact during a fire.

## **4 EVALUATION OF POSSIBLE SOLUTIONS**

To evaluate the functionality and safety level of the solutions identified in the previous section, quantitative risk analyses using fault tree analysis are carried out in which the different designs are compared with the simplified design approach according to Swedish Building Regulations, BBR [3]. The statistics used in the calculations are taken from “*Effectiveness of Fire Safety Systems for Use in Quantitative Risk Assessments*” [5]. The material is based on a literature review that compiles statistics from several sources and includes fault tree analyses used to evaluate the performance of different systems in buildings.

The test data from the measurements presented in 1.4 show a clear thermal inertia in the cooling of firefighter elevator shafts at low outdoor temperatures. This inertia results from both the pressurization system and the concrete structure of the shaft, creating a noticeable temperature difference between the outdoor environment and the shaft. It can also be observed that this difference increases as outdoor temperatures decrease.

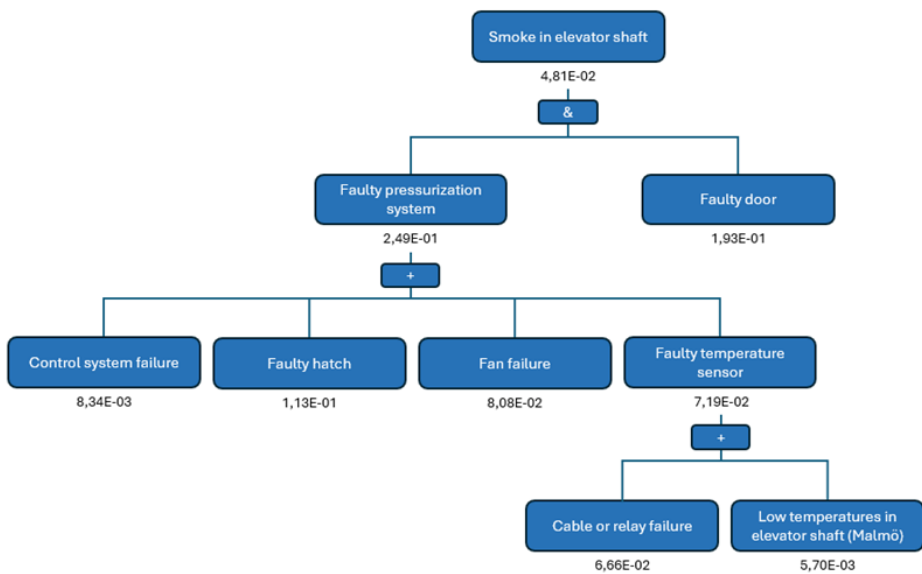
As mentioned above, in the test with the lowest outdoor temperature (approximately  $-11\text{ }^{\circ}\text{C}$ ), the shaft temperature remained above  $0\text{ }^{\circ}\text{C}$  even after 60 minutes of pressurization, with an airflow supply rate of  $4\text{ m}^3/\text{s}$  and a fan located outside at the top of the elevator shaft. Therefore, either lower outdoor temperatures or higher pressurization airflow rates would likely be required for sub-zero temperatures to occur in the shaft.

In the following calculations, it is assumed that pressurization using a fan placed directly at the shaft, with an outdoor temperature of  $-8\text{ }^{\circ}\text{C}$ , may risk causing sub-zero temperatures in the firefighter elevator shaft. This value is considered to account for uncertainties in the data as well as the possibility of higher airflow rates during pressurization. However, it should be noted that for significantly higher airflow rates than  $4\text{ m}^3/\text{s}$ , the validity of this assumption may need to be reassessed. The statistical probability of outdoor temperatures falling below  $-8\text{ }^{\circ}\text{C}$  at the locations analyzed in section 5 is presented in Table 1.

**Table 1.** Probability of temperature being below  $-8\text{ }^{\circ}\text{C}$ .

| Town       | Probability < $-8\text{ }^{\circ}\text{C}$ |
|------------|--------------------------------------------|
| Malmö      | 0.57 %                                     |
| Gothenburg | 1.18 %                                     |
| Stockholm  | 2.43 %                                     |
| Umeå       | 10.11 %                                    |
| Luleå      | 14.47 %                                    |

In Fig. 2. an example of a fault tree analysis presented.



**Fig. 2.** Example of fault tree analysis of a PBD-solution with cold temperature included.

The following scenarios were analysed using fault tree analysis:

- Shutdown of the pressurization fan at low temperature
- Pre-heating of air using an external heat source
- Pre-heating of air through the duct system
- Reduction of fan capacity at low temperature
- Push/pull system where the fan supplying the firefighter elevator is shut off at low temperature

The fault tree analysis shows that the risk of smoke contamination varies depending on the system design and implemented measures. For buildings with two, or more, fire rated doors between the potential fire compartment and the firefighter elevator, combined with a pressurization system with a constant-speed fan, the risk of smoke spread is generally lower than in a design based on simplified design according to regulations. This remains valid even when the fan is shut off if low temperatures in the elevator shaft occur.

In designs where only a single fire rated door separates the potential fire compartment from the firefighter elevator shaft, the risk of smoke spread with pressurization alone is roughly equivalent to the reliability in the prescriptive solution in the building regulation. However, this may change when measures to address low shaft temperatures are introduced. Overall, the analysis indicates that in southern Sweden only limited additional measures are required to maintain a safety level equivalent to simplified design, whereas further measures may be necessary in northern Sweden.

## **5 Discussion**

The study performed is, like all studies, associated with certain assumptions and limitations. The most important of these are discussed below.

Due to the limited availability of reliability data for Swedish pressurization systems, fault tree analyses were based on a single international data source to ensure methodological consistency. Given Sweden's regulatory requirements for inspection and maintenance, the actual failure probabilities are expected to be lower than those assumed in the analysis, making the results conservative.

The evaluation of mitigation strategies indicates that, for many Swedish buildings, relatively simple measures can effectively manage the risks associated with low temperatures. Installing a temperature sensor within the lift shaft together with a manual override for the pressurization system provides an appropriate baseline level of protection in most cases. However, additional measures may be required in northern Sweden. This could include the incorporation of fire rated doors between the firefighter lift and/or sprinkler protection systems to ensure proper protection of the elevator shaft. This is especially important for systems using pressure-controlled fans, which show lower reliability in general. In residential buildings, the presence of double fire protected lobbies between apartments and the lift shaft generally provides a level of protection comparable to prescriptive design requirements, even if the pressurization system is shut off during low temperatures.

The cost-effectiveness of mitigation measures depends strongly on the specific building and system configuration. Solutions based on heating the supply air are generally considered less economical because heating demand varies substantially with system design and may require costly upgrades to the building's electrical infrastructure. In many cases, alternative design

measures, such as optimized duct routing or the presence of sprinkler systems, can provide the required level of reliability at considerably lower cost.

## 6 Conclusion

In summary, the following conclusions and recommended measures are given based on the research summarized above:

- A temperature sensor should be installed in the elevator shaft that shuts off power to the pressurization fan if the shaft temperature remains below 0 °C for more than 60 seconds. This measure is recommended regardless of the chosen solution, since the elevator's operational safety cannot be guaranteed at sub-zero temperatures. The sensor should be located approximately two floors above (or below, depending on system configuration) the air supply point. An indicator light should also be installed at the firefighter control panel (or equivalent) to show when the temperature sensor has been triggered.
- The pressurization system should include a manual control relay (1–0–auto) as an alternative activation method to increase system reliability. In situations where the fire alarm signal fails, this allows emergency responders to activate the system manually. This functionality has been described in a previous Swedish research report [6], and its benefits are also confirmed by the calculations in this report. The manual control relay must not override the shaft temperature sensor.
- For buildings with two fire rated doors between the firefighter elevator shaft and areas where a fire may occur, combined with a pressurization system, the probability of correct system function is at least equivalent to prescriptive design solutions even if the pressurization fan is shut off during low outdoor temperatures. This applies to all five analyzed Swedish cities (table 1), provided that both the temperature sensor and manual control relay are installed as described above.
- In buildings with only one fire rated door between the firefighter elevator shaft and a potential fire compartment, the probability of low outdoor temperatures becomes more significant. Required measures vary geographically due to different likelihoods of sub-zero temperatures occurring. For systems in Malmö, Gothenburg, and Stockholm, installing a temperature sensor in the shaft together with a manual control relay results in a design that provides a safety level at least equivalent to simplified design. For systems located in cities where the probability of outdoor temperatures below –8 °C exceeds 3.5 % over the year—such as Umeå and Luleå—additional measures are required. Possible measures include longer indoor duct paths, air heating systems, sprinkler protection systems and/or added fire compartmentation.

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