Lodz University of Technology

EPS Project

Fire Strategies in Buildings

LabFactor fire strategy

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ABSTRACT

Nowadays, fire strategies play a significant role in fire engineering. They are constantly being improved while fire engineers develop new solutions and provide more ideas to protect people´s lives. The project was focused on evaluating a fire strategy for the LabFactor building at the Lodz University of Technology. In the process, the latest approaches to fire strategies were used as well as Fire Dynamics Simulations and practical smoke tests. The project yielded meaningful results concerning smoke control and ventilation systems installed in LabFactor such as the effectiveness of smoke curtains and atrium smoke exhaust fans. The report illustrates the research done for the needs of the project as well as the outcomes and findings arising from the aforementioned tests and simulations. Conclusions and recommendations present the observations after five months of work on the assessment of LabFactor´s fire strategy. Although the current fire strategy gives positive results, taking into consideration the remarks contained in the recommendations would improve the strategy even further, potentially leading to saving more human lives.

1. ABOUT US

1.1. TEAM MEMBERS

MICHAŁ KĄCKI

My name is Michał Kącki, I am 21 years old, Polish and I study Information Lodz University of Technology. The main area of interest connected with my field of studies involves machine learning, which I am planning to major in. I have decided to choose the topic of Fire Strategies in Buildings to widen my horizons by trying out something completely new to me. Before, I have not had any experience with fire engineering apart from a few fire drills in which I participated. Nowadays, fire engineering is inextricably associated with computer science so the rapid development of computer engineering makes the work of fire engineers at least slightly easier. I think it was a great opportunity for me to see how my future Information Technology achievements can be applied in the vast world of other engineering fields.

GERARD VIVES MUÑOZ

My name is Gerard Vives Muñoz and I am a 21-year-old Mechanical Engineering student from the Polytechnical University of Catalonia. During my studies, I have gained knowledge about Fluid Mechanics, Thermodynamics, and Structural Calculations among other interesting subjects. This led me to choose this project, as fire and its consequences are directly related to all these subjects. I am passionate about exploring other fields which I can work in - or have to deal with - at some point of my career. My knowledge in CAD is also useful for this project, as we will have to deal with plans and computer simulations. Apart from this, I am planning to continue with a Master's Degree on Automotive Engineering.

SAAD MUGHAL

My name is Saad Mughal, I am currently 21 years old and I study Computer-Aided Mechanical Engineering at Glasgow Caledonian University. I specialize in CAD software, such as Creo and ANSYS, Arduino programming, thermodynamics, and fluid mechanics. I became attracted to engineering due to the rapid advancement of technology in recent years. I am also interested in pursuing other fields, such as civil or automotive engineering. Introducing myself to the world of fire engineering will be a great experience for me as I aim to gain useful knowledge from the "Fire Strategies in Buildings" project. I chose this project because I would like to see if fire engineering is a possible future option for me. My past experiences of using Creo and ANSYS may become beneficial for the project in terms of simulating and designing.

ALBERT KUŁAKOWSKI

My name is Albert Kułakowski. I am 22 years old, Polish and I study Information Technology at the Lodz University of Technology. I am an active participant of Student Government of TUL. In case of the field of my studies, I am mainly focused on programming in C++ and Python. Understanding all aspects and techniques used in creating applications provides me with knowledge which can be used in different fields of studies (for example in fire strategies). Apart from technical skills, my business knowledge helps me to work within a group and gaining any benefits from it.

1.2. TEAM NAME AND LOGO

Figure 1 - Team logo

The design of the logo has been created after the Hindu god of fire, ‘Agni’. According to Hindu mythology, Agni is not only the creator of fire but also the protector of mankind. Those two elements combined fitted perfectly for the needs of the project.

A flame above the ‘I’ letter from ‘Agni’ emphasises the topic of the project. The word ‘*solutions*’ has been designed to give a refreshing feeling to the observer, using blue letters, which is usually the colour associated to water, the opposite element to fire. The two blue and orange stripes above and under the logo are a representation of the duality of those two elements -water and fire-.

Finally, the slogan meaning is a clear, direct way to tell the observer that a good fire strategy can literally save lives in a fire situation.

2. OBJECTIVES AND GOALS OF THE PROJECT

The main objective of the project was to evaluate current LabFactor fire strategy using the newest methodologies in the field. The already developed fire strategy was assessed using older methodologies which are becoming more outdated and less effective. LabFactor is an interesting building because it features a very popular concept in contemporary construction, namely an atrium, generally difficult to protect from the dangers of fire. LabFactor was chosen for one more reason - it is also a place where Laboratory of Smoke is located so majority of fire strategies can be tested not only using simulations and pure theory, but also utilizing real equipment.

The goal of the project was to learn about new fire strategy methodologies and apply them to the aforementioned problem of LabFactor's atrium under the supervision of experts in fire engineering. With that knowledge various simulations of fire case scenarios in the building were conducted. Based on them, theoretical assumptions were checked. Conclusions were determined from those results, as well as from the practical smoke tests, and they were used to arrive at the outcome of the whole project.

3. INTRODUCTION TO FIRE ENGINEERING

3.1. INTRODUCTION [1]

Historically, fire strategies have been designed in order to protect lives and in accordance with the law. This, which may seem the correct thing to do, has been proved not to be enough as it does not consider a variety of other factors. The environment, the economy and the properties of the affected area can also be extremely damaged as a result of a fire and need to be considered.

As a result of this, new fire strategies can be as diverse as the number of buildings on the planet. It is the task of the fire strategist to constantly ask “Why?” when creating the strategy, even if the answer may seem obvious. The reason is that the other stakeholders taking part in it (architects, engineers, building owners) may have their own reasons to do it one way or another, and asking “Why?” may bring up some thoughts or ideas which could be taken into consideration. We must be aware that some of them will only want to be accordance with the law, even if that would result in a non-practical design. Then again, it is the task of a fire strategist to confront this approach.

New fire strategies have to consider all these elements to create the best design, a design which minimizes the losses and takes into account law accordance, occupants fire training, building aesthetics, etc.

The next diagram gathers all the factors that must be present when creating a fire strategy:

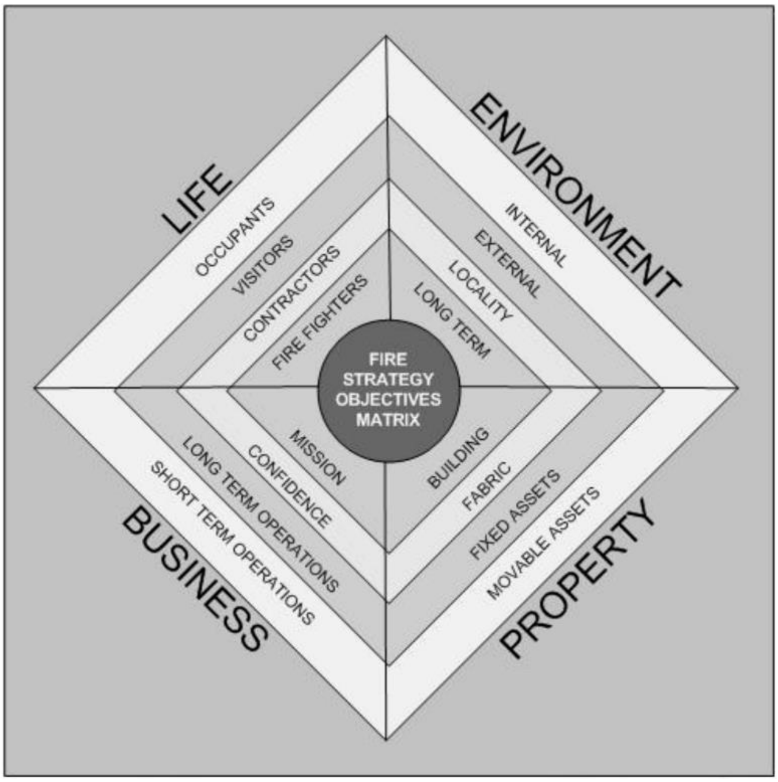

Figure 2 - Fire strategy objectives matrix

3.2. LIFE SAFETY [1]

- **Building occupants.** The main objective of life safety strategies are building occupants. Fire safety legislation is designed to ensure normal occupants of a building are kept safe from a fire and can evacuate safely. In many cases, by meeting the legislation the occupants' life safety is covered.
  The fire strategist may even consider their profiles, level of disabilities, language issues, etc. to get a deeper evaluation.

- **Visitors.** It is very likely the visitors have a different profile of the occupants, which usually implies little knowledge of the building. In many cases, visitors represent a small proportion of the overall occupancy. However, in places such as airports, railway stations or sport stadiums the majority of the occupancy counts as visitors. Consequently, fire strategist should consider different criteria regarding to the number of visitors.

For this, it must be considered the worst-case scenario. That is, the maximum possible number of people. Also, visitors may be spread unevenly across the building, creating some areas with higher concentrations.

- **Contractors.** Contractors are people who work on or in the building for maintenance or construction purposes. For them, the evacuation time is different than the rest of building occupants. This is due to the fact that a contractor may be up in a ladder or in a confined space when the alarm is raised. We must consider then how the alarm message arrives to those places and how much extra time does the contractor need to reach a safe place. In order not to make the strategy over-complicated, only the places where people could be in a regular basis should be considered.

- **Firefighters.** If the fire strategy only considers the life safety of the occupants and there is no need for the firefighters to assist in any way, the safety of the firefighter can be obviated. For all other cases, anything such as the accessibility to every level of the building or advanced fire compartmentation will need to be taken in account.

3.3. PROPERTY PROTECTION [1]

- **Building.** As it is obvious, it is required that the strategy is designed to protect the structural parts of the building or the whole building itself.

- **Linings of the building.** Some linings of the building can be more valuable than the building itself. Frescos are a great example of this. The fire strategist should consider these elements, and the fact that they can be damaged not only by the fire but by the smoke too.

- **Fixed assets.** Referred to those elements that may have an intrinsic value but cannot be moved easily. A different approach must be taken for these elements to protect them. Good examples are computer servers or manufacturing equipment.

- **Movable assets.** The best example would be works of art. For these extremely valuable elements, it is justified to have a special consideration.

3.4. BUSINESS PROTECTION/INTERRUPTION [1]

Apart from the devastating effects a fire can have in the structure of a building, the consequences on the business itself can also make a company go bankrupt. This can be explained by all the logistical damage caused: in the direct aftermath of a fire, clients may not enjoy the level of service they would usually get, suppliers may find more difficult to deal with the business, etc.

To avoid or reduce this decline, there are a few sub-objectives that should be considered.

- **Short-term operations (today, tomorrow and next week operations).** Even if the business continuity plan does not involve or require fire protection or fire safety management, it may be necessary to consider one as some elements may require protection from fire or the effects of fire.

- **Long-term operations.** A quick fix on the aftermath of a fire (such as switching manufacturing to another plant) may guarantee the survival of a business for weeks or months, but it may not be a realistic solution for the next years to come. A single fire should not affect how a business operates.

- **Client confidence.** As a result of a fire, confidence loss can lead to bankruptcy of a business, especially in the ones with mass visitors. This can be easily explained as customers will not go to places where their life may be threatened in case of a fire (for example, to a football stadium where there is a real risk of fire). In these cases, fire strategy should be more focused on prevention and management rather than relying on fire protection.

- **The mission.** A fire can raise questions about the business itself. Would customers trust a fire safety teaching establishment that just suffered a devastating fire? Or imagine an explosives manufacturing industry suffering the same fate… Would they have any kind of trust from their clients? Those type of businesses should have an extremely well-prepared fire strategy.

3.5. THE ENVIRONMENT [1]

Nowadays, the environment is rarely considered in most fire strategies. However, as it is very likely the legislation will move towards more strict laws on this subject, it is necessary to explain the need of a good environmental plan in case of fire.

- **Internal impact.** It is very important to identify the risks of the products released into the air during a fire, and when talking about internal impact, the ones that will stay inside the building during and after the fire. This is, how any chemical products can circulate through the building or how products of combustion can contaminate anything such as stock, consumables, etc.
  Also, secondary contamination must be taken in account. A good example is water pollution due to combustion waste and its health and economical costs (Is it safe to consume it? How much money will be needed to do an intensive clean-up?)

- **External impact.** The area surrounding the affected building will probably suffer a big negative impact, from burned cars to radiative heat to the surrounding buildings, as well as human and animal life/health costs.

- **Neighbours' impact.** Some considerations here are the fire plume or airborne contaminants impact on the local community, which are less controllable as it depends also on the weather and the geography of the zone (underground water channels can get polluted as a result of chemicals release from a fire, affecting local people and animal's health).

- **Long-term impact.** It is more difficult to quantify, as it is more subjective than the previous ones. However, a good strategy should consider different scenarios for the next months or years in the aftermath of a big fire, and how can that affect the local, regional and national ecology. A good example is the oil spills produced during fires in off-shore oil platforms, and how the ecosystem of a region can be affected for decades.

There are many ways in which a fire can cause damage but choosing the more relevant ones will turn a regular fire strategy plan into an efficient, effective and cost-reducing one. It is the task of the fire strategist to have this approach on the matter.

3.6. PERFORMANCE AND PRESCRIPTIVE-BASED SOLUTIONS

When it comes to dividing fire engineering design, two different solutions can be distinguished. Namely, performance- and prescriptive-based approaches.

The performance-based approach to fire safety design relies on the use of fire engineering principles, calculations and/or appropriate software modelling tools to satisfy the intentions of the Fire Code which newest edition is currently the 2018 version. This fairly new approach provides alternative means of meeting the intentions of the Fire Code. The building practitioner will need to substantiate that the proposed solution fully meets the intent of the Fire Code using established fire safety engineering methodology. [2]

A prescriptive method defines a structural fire design fairly precisely in terms of the materials used, shape and size of structural elements, thickness of fire protection materials and construction details etc. Traditionally, the design recommendations are mainly based on the experience with identical or similar standard fire tests. This concept works very well in a static situation but inhibits innovation and development of construction industry. It can become very restrictive in situations where designs need to evolve to meet architectural or aesthetic requirements. For these reasons, the prescriptive designs have been evolving for many years towards the performance-based designs. [3]

The main reason why performance-based solutions have been introduced in fire engineering is the development in construction industry. Every year more and more complex and strangely looking buildings are designed and eventually built. Their structures are often so complicated that they confuse fire engineers as it is extremely difficult, sometimes even impossible, to apply old solutions taken from the Fire Code. However, those buildings comply with building code and there is nothing that can be done - they have to be well-protected from fire situations if they are to be erected. It is worth mentioning the fact that complex interiors are gaining in popularity. Their elaborate layout does not make fire engineers' work easier. Even a simple atrium can be a real challenge to a qualified specialist because of its specific open space design which is perfect for spreading clouds of smoke. [4]

Figure 3 - Kunsthaus in Graz, Austria

Figure 4 - CCTV building in Beijing, China

Figure 5 - The Crooked House (Krzywy Domek) in Sopot, Poland

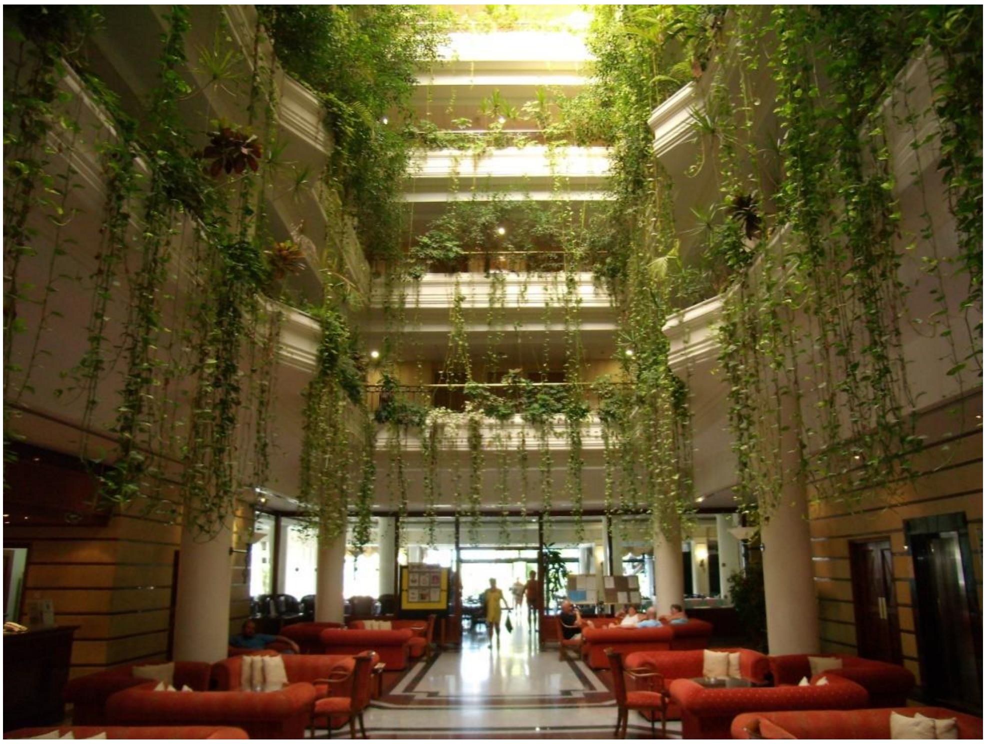

Figure 6 - An example of an atrium

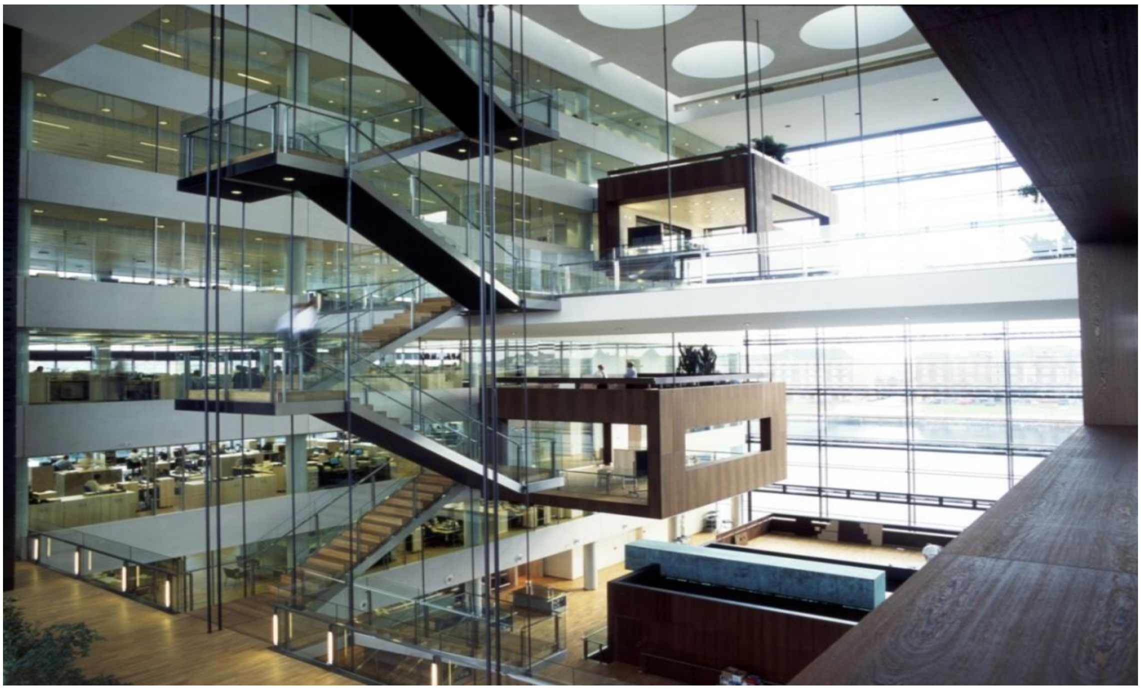

Figure 7 - Another example of an atrium

3.6.1. Performance-based approach [2]

A performance-based method focuses on mathematical calculations and results from conducted simulations. It is the application of science and engineering to design fire protection and life safety systems in buildings, taking into account the specific characteristics of the building under consideration, rather than applying generic "checklist" requirements found in prescriptive building and fire codes that may not be appropriate due to a building's unique characteristics.

In this approach, various candidate designs are thoroughly examined using engineering calculations (such as computer fire modelling) to evaluate the influence of different fire scenarios on the considered building and people in it. Each of the designs might (and probably should) include different variations of fire protection systems (e.g. sprinkler types, smoke detectors, distribution of flammable materials in the building).

Typical tools used in performance-based fire-code implementation are different modelling techniques which show the behaviour of various elements present in a building during a fire. For example, simulations of smoke plumes travelling through different rooms or of a massive fire in a dangerous place like a laboratory full of chemicals or an atrium.

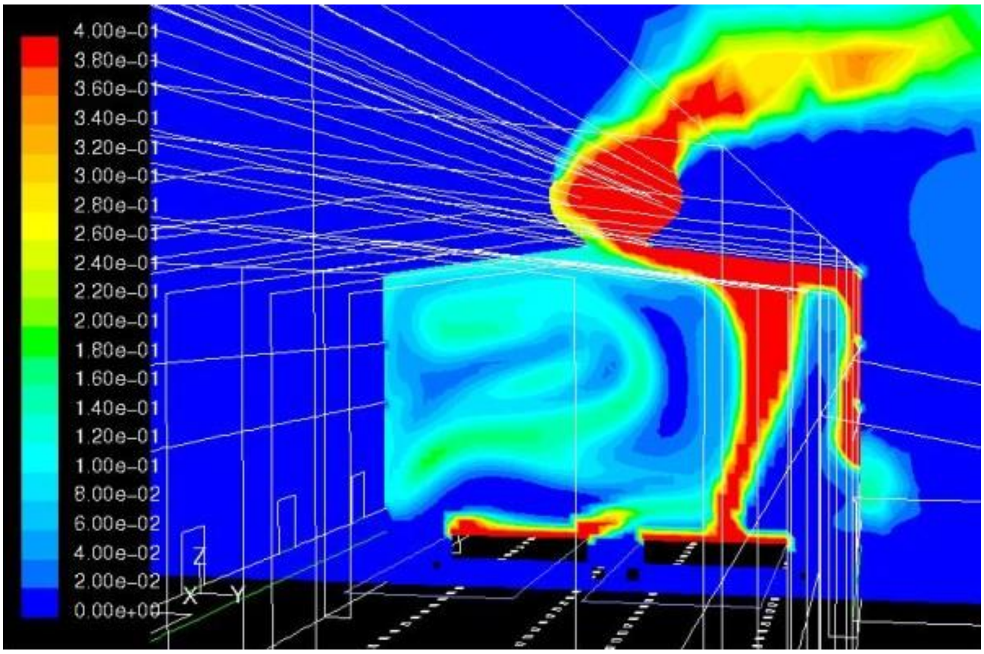

Figure 8 - Computational fluid dynamics (CFD) simulation of smoke plumes

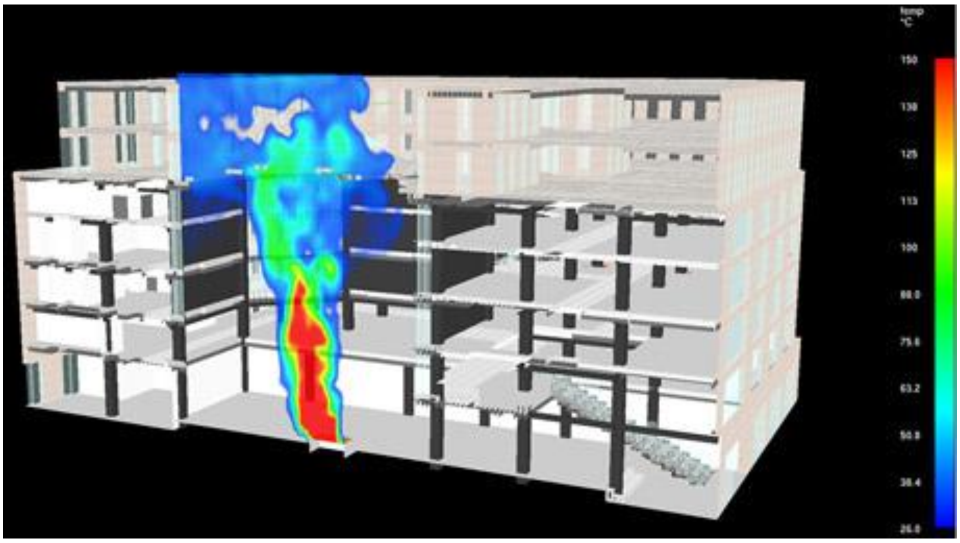

Figure 9 - Computer simulation of fire in the atrium

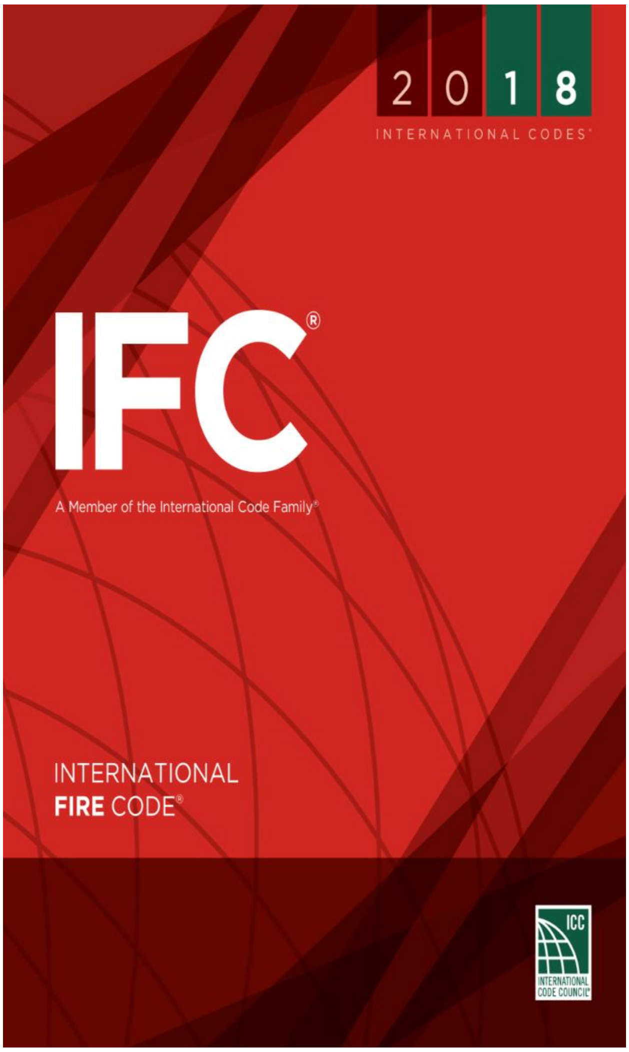

Figure 10 - Cover of the International Fire Code

3.6.2. Prescriptive-based approach [3]

The prescriptive-based approach, as stated before, is all about sticking to regulations and testing the materials used in construction of the building which are to be protected from fire. The current prescriptive rules for designing the fire resistance of steel, concrete, masonry and timber members are based solely on the results and observations from standard fire resistance tests.

Generally, in such a test a structural element is placed in a heated furnace environment for the desired time. The resulting fire resistance rating is expressed as the time in minutes that the element is able to withstand in that environment until some dangerous failures appear. Based on these tests, structural elements are classified into fire resistance categories. The number of tests necessary for classification varies from country to country.

Normally, gas burners are used to create the environments which simulate fire situations. Traditionally, the prescriptive approach developed from the standard fire tests have proved to be an adequate and effective for ensuring a minimum level of fire safety to buildings. The direct application of the fire test results can be easily understood and applied by designers and checking authorities.

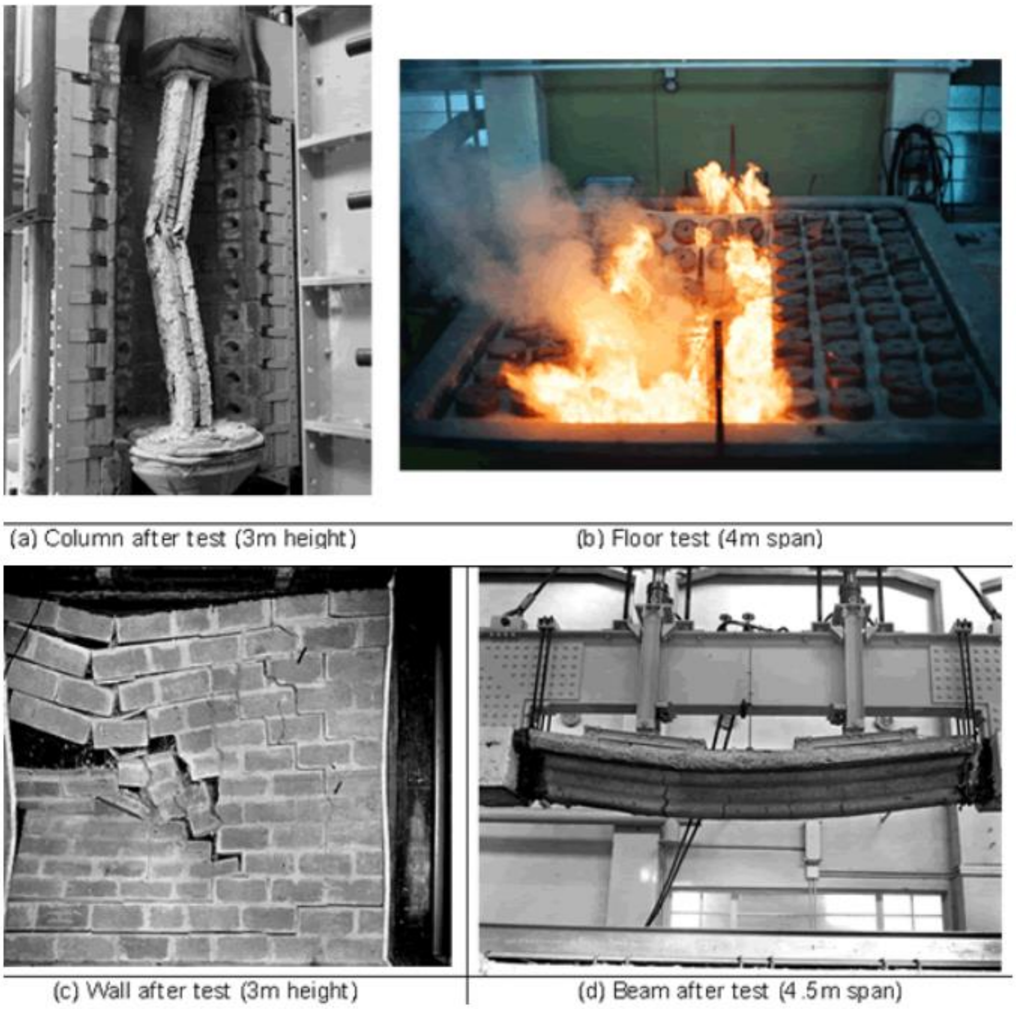

Figure 11 - Some pictures presenting standard fire tests

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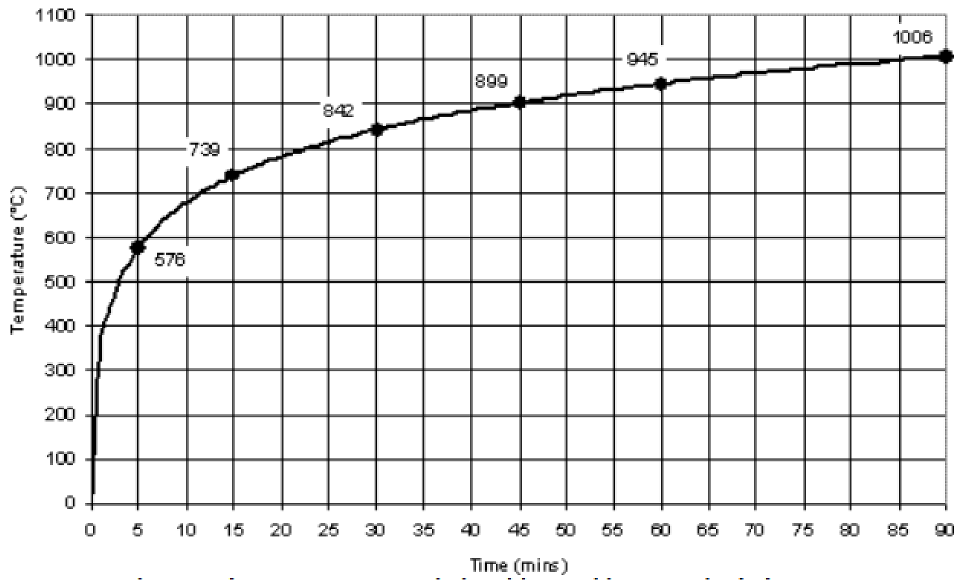

Figure 12 - Time-temperature relationship used in a standard fire test

However, this method has generally been considered to stifle the fire engineer's understanding of how buildings behave in fire. The main limitations include:

1. Structural elements in a fire test are checked separately which does not show the real situation when many different parts of the building are connected. Workload is not being taken into consideration as much as a fireproofing rating.
2. The charts showing fire curves have been developed based on many years of experience, but it is still not enough. Every fire can be different in its behaviour and it is possible that it will not behave in an estimated way. Also every building has different height, cubature, layout and equipment present in it, which can make the results of standard fire tests irrelevant.
3. The development of prescriptive-based approach is still an ongoing process. However, many regulations are outdated and can be even 20 or 30 years old. Taking into consideration the rapid development of every aspect of people's lives, such regulations are not enough.

To clearly understand differences between the two aforementioned approaches it is crucial to notice that prescriptive-based solutions involve applying rules from the Fire Code and gaining knowledge from standard fire tests, whereas performance-related methods focus on the results of computer simulations, mathematical calculations and also imaginative thinking of fire engineers.

Like in the case of passive and active fire protection more than one solution has been presented so once again it is imperative to ask which solution is better and if we can do without the other one.

As mentioned above, a fire heated structural element in a building does not behave in an isolation manner. The interaction of the heated elements with the rest of the building can cause thermal stresses which are not taken into consideration during fire tests. Ideally, the tests should be conducted in full-scale. However, it is very difficult and expensive to conduct satisfactory tests for some complicated connections between elements and due to that fact, the standard approaches have evolved towards a hybrid between prescriptive and performance-based concepts. [4]

3.7. STRATEGY VALUE GRID [1]

One of the ideas allowing a quick and easy way of picturing a way strategy. Ideally the picture should be apparent using one side of A4 paper. This method is captured in a diagram and has been designed to identify the main elements of the fire strategy. Main goal of the diagram is to identify how they believe each element contributes to the overall fire strategy. It allows identification of the relative value of each of eight elements appropriate for every fire strategy.

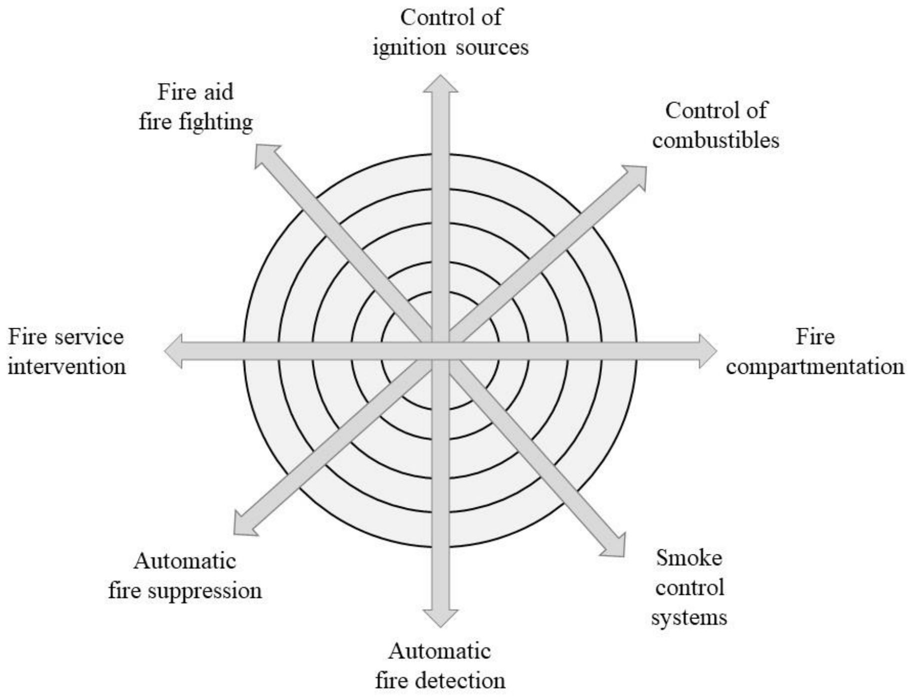

Figure 13 - Graphical form of strategy value grid

As you can see, on grid there are eight key strategic factors:

1. Control of ignition sources
2. Control of combustibles
3. Fire compartmentation
4. Smoke control systems
5. Automatic fire detection
6. Automatic fire suppression
7. Fire service intervention
8. First aid fire fighting

The idea of the diagram is to allow each of the eight factors to be separately considered and scored from zero to five (sometimes 25), based on their relative importance to the strategy.

3.7.1. Control of ignition sources and combustibles [1]

Combustibles materials can exist within building in form of stored materials, production equipment etc. Ignition sources may be found throughout the building. Fire strategist needs to understand possibilities and probabilities of main sources of ignition and how they could combine with potential fuel sources. Control of ignition sources and combustibles depends on proper safety management. There is some building that are full of ignitable materials. There are ways to overcome this by replacing the materials with less flammable version. sometimes this may not be acceptable to stakeholders.

3.7.2. Fire compartmentation [1]

Partition of building on fire areas, known as passive fire protection, is probably first of fire protection methods. The three key reasons for compartmenting one area from another are:

- To contain or control a fire for long enough to allow evacuation of persons from the building.
- To contain or control a fire for long enough to allow for time to suppress or extinguish the fire by automatic or manual means.
- To control the cubature engulfed in flames in the way to contain the fire until it is starved of oxygen.

3.7.3. Fire detection [1]

Automatic fire detection is often considered a cornerstone of any fire strategy. Fire detection systems are fire monitoring systems to initiate warning systems or control fire protection systems. A strategy that does not include the need for automatic fire detection is not in the realms of fiction but possible in limited cases. There is possibility to create fire strategy relying totally on a first-rate fire safety management. It also happens, that using fire detections is really hard or even unable to use it in terms of technological issues.

3.7.4. Smoke control [1]

Smoke control aims to provide objectives like: protecting the escape routes and facilitating firefighting. The simplest methods of controlling smoke are opening a window or vent. This may provide some relief, but in most cases, this will not be enough. The essence of smoke control systems for life safety purposes is to keep escape routes free from smoke. This does not mean that all smoke will need to be extracted for the required period but just enough to ensure visibility to escape. Hence, smoke should be above head height. This means that for automatic smoke extract, we will need to know with sufficient accuracy how much smoke is likely to be produced. But in real life we cannot be absolutely sure of the fire size. We should consider worst-case fire size. Furthermore, automatic smoke extract systems work best when the smoke is hot, so that is raised vertically and can be extracted at a high level.

3.7.5. Fire suppression systems [1]

There is a vast array of methods to suppress fire and more ideas and techniques are being developed all the time. Note that term fire suppression is used rather than fire extinguishing. This is based on the idea that the system may primarily be used to control and keep the fire in a controlled state until is can be fully extinguished or until it can be confirmed that it has been fully extinguished.

3.7.6. Fire service intervention and first aid firefighting [1]

Sometimes we assume that the intervention from the State fire brigade service is given. It is often assumed that the fire brigade will be in attendance in couple of minutes. There assumptions are wrong and leads to misunderstanding. It is necessary to be ensured that the firefighting infrastructure is available for the firefighter to utilise. To check the process from arrival to fighting the fire is as smooth as possible. Consider where the firefighters will arrive, how will they be met? How will they access the building, including upper and basement areas?

3.8. FIRE PREVENTION AND FIRE PROTECTION [5]

What is fire prevention? It involves taking precautions to prevent potentially harmful fires and how to survive them. It is very important for everyone to know how to deal in the situation of a fire as it can occur at any time. Many departments and companies hire a Fire Prevention Officer who excels at fire protection and safety and educates those around them.

Target audiences for fire prevention are usually students, senior citizens and landlords. Firefighters and fire prevention officers will often visit schools and educate students on the necessities of fire prevention. This is very beneficial as it is very useful to learn how to deal with a fire and the evacuation procedures from a young age. The most basic procedure to follow when clothing catches fire is the stop, drop and roll. When caught on fire, one must stop, drop to the ground and roll back and forth to extinguish flame. Running will simply fan the flames. Senior citizens are identified as an “at risk” group, especially in hazardous situations due to most of them being handicapped. It is vital that seniors have pre-planned their escape routes and have easy access to emergency exits. For landlords, it is important to implement fire prevention and fire safety measures for the wellbeing of their tenants in many jurisdictions. Once a building has been constructed, it must be maintained in accordance with the current fire code, which is enforced by fire prevention officers of a local fire department.

Smoke detectors are another type of fire prevention. A smoke detector is a device that senses smoke. Smoke detectors reduce the chances of death in a fire by half. Deaths in a fire have decreased by half since the invention of the smoke detector. Smoke can be detected optically (photoelectric) or by physical process (ionization).

What is fire protection? This is the study and practice of alleviating the unwanted effects of potentially destructive fires. An example of fire protection are wet-pipe sprinkler systems. These automatic sprinkler systems are usually employed in which the supply valves are open and the system is charged with water under supply pressure all the time. This is utilized because of its ability to get water the quickest on the fire and being easy to maintain.

Type of Fire	European	North America	Australia
Fires that involve flammable solids	Class A	Class A	Class A
Fires that involve flammable liquids	Class B	Class B	Class B
Fires that involve flammable gas	Class C	N/A	Class C
Fires that involve combustible metals	Class D	Class D	Class D
Fires that involve solids and liquids with the introduction of electrical appliances	Class E (currently no longer in the European standards)	Class C	Class E
Fires involving cooking fats and oils. Normal extinguishing agents are ineffective due to the high temperature of oils whilst on fire.	Class F	Class K	Class F

Table 1 - Classification of fire types

3.9. WHAT SHOULD BE DONE IN CASE OF FIRE

It is widely known that fires can be devastating, especially in lives costs. Sometimes, when a fire strategy has not been properly developed, we can find ourselves in the middle of a dangerous situation. In order to take the minimum risks, it is very important to know the basics of how to deal with it, in this case, with a fire scenario.

3.9.1. Fire-related deaths overview

In Poland, more than 600 people die every year in fire-related accidents.

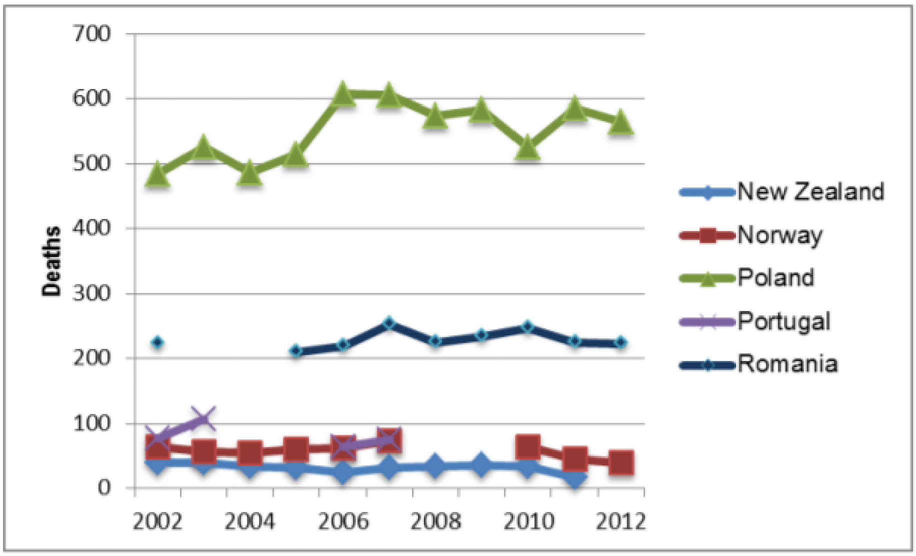

Figure 14 - Fire fatalities per year in NZ, Norway, Poland, Portugal and Romania

At first sight, this graphic may seem a lot of deaths -which they are- but we must take into account the number of total inhabitants in the country.

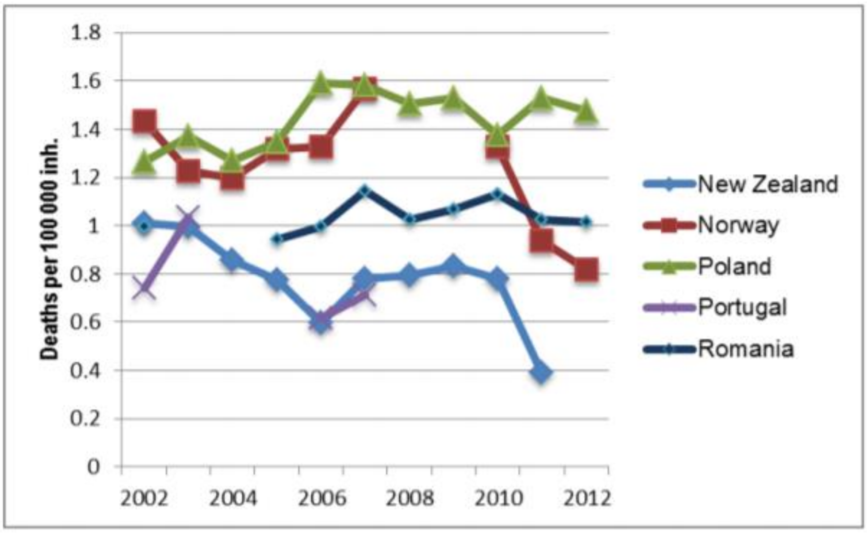

Figure 15 - Fire death rates per capita in NZ, Norway, Poland, Portugal and Romania

This means that approximately 1.6 people die per every 100.000 inhabitants in the country, situating Poland at the same rate as Norway.

These statistics, even though they are pretty low (we could think good fire strategies have been applied in this country), means that every year 600 families are suffering the consequences and should be reduced, eventually, to 0.

3.9.2. Main causes of death in a fire scenario

Even though we could think of fire itself being the main death cause, it is not. Carbon monoxide inhalation is the main reason of deaths, as it makes a person pass out very quickly and ends up replacing the oxygen with monoxide particles.

The second cause of death is carbon dioxide inhalation, acting very similar to the previous one.

The third cause is due to the heath shock produced during a sudden fire. It is the same reaction the body has in very hot summer days, when a person can pass out or even die if not treated correctly. During a fire, this can certainly lead to death as the possibilities to reach for an exit are drastically reduced.

Direct injury from the flames is the next cause in the list, and it is self-explanatory. Finally, death from injuries during hospitalization is the last cause of death.

3.9.3. What to do in case of fire [6]

- Step 1. **Don't panic**. As difficult as it may seem, try not to panic, as it will only narrow your mind and vision. A clear mindset will allow you to take the best decisions at every moment, which in situations like this can save your life or the ones around you.

Figure 16 - Panic attack

- Step 2. **Tell everyone!** Whenever you encounter a fire, make sure everyone around you are aware of the danger as you reach for the exit. Blind, deaf, children or the elderly are especially vulnerable in these situations.

Figure 17 - Tell everyone!

- Step 3. **Stay low!** As mentioned before, carbon monoxide (which is contained in the smoke) is the main cause of death during a fire. The best way to avoid inhaling too much smoke is by keeping your head as low as possible, as smoke will keep on the ceiling.

Figure 18 - Stay low!

- Step 4. **Look for emergency exits**. During fires in crowded places (a school, a concert, and a shopping mall) it is our instinct to follow other people. But sometimes that does not mean being in the right escape route. Before taking any action, try to figure out where the nearest emergency exit is and focus on taking that way.

Figure 19 - People fleeing a concert during an emergency situation

- Step 5. **Call emergency services**. Once you reach a safe place, be sure to call emergency services immediately. Every minute counts and other people's lives could be saved by your phone call.

Figure 20 - Emergency call

3.10. PASSIVE FIRE PROTECTION [7]

Basically, passive fire protection (PFP) is a part of several crucial components that form the overall structural fire protection and fire safety in buildings. The other two are active types (e.g. sprinklers & hoses) and non-active (e.g. alarms & detectors). One of a few definitions says that: *"Passive fire protection is a group of systems that compartmentalise a building through the use of fire-resistance rated walls and floors, keeping the fire from spreading quickly and providing time to escape for people in the building."* While it might not be the most accurate definition, it gives a decent overview of what passive fire protection really is.

The aims of PFP are rather clear and simple. Its three main objectives are as follows:

- Protection of human life,
- Protection of property,
- Granting the possibility of continuity of business operations.

Each of the aforementioned aims is extremely important and costs a lot if is not made sure that every one of them has been properly taken care of.

There are four main ways of enforcing passive fire protection and those are:

- Cavity barriers,
- Intumescent coatings,
- Boarding systems,
- fire-resistant glass.

3.10.1. Cavity barriers [8]

Cavity barriers are a special type of fire walls installed in concealed spaces to limit the spread of fire, smoke and hot gases to other parts of the building. When buildings are erected some space between adjacent walls must be left. This is driven by some structural reasons which are very important from the point of view of architectural engineering. Paradoxically, those cavities can be very dangerous during a fire because if it occurs, they become channels which fire and smoke will use to travel further and essentially to spread. Cavity barriers can protect parts of the building that are not yet ablaze. They may be made from different materials (always non-flammable, e.g. mineral wool), look differently and serve various purposes. Most popular types of cavity barriers include static layers made of incombustible material and more modern and innovative special tapes. Those tapes do not take much space, but they expand when exposed to high heat effectively filling holes and cutting off flames and smoke.

Figure 21 - An example of a static fire wall

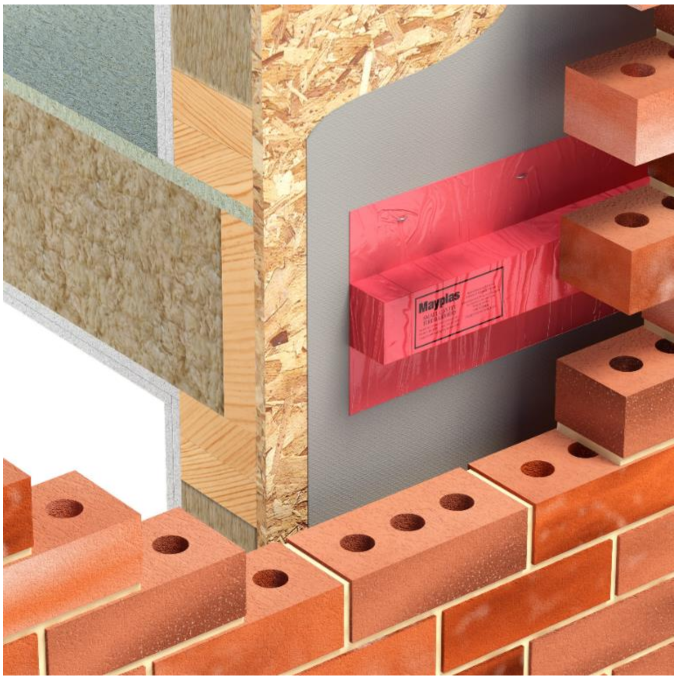

Figure 22 - An example of a cavity barrier in a form of a tape

Fire walls are crucial in passive fire protection and the best example to prove that statement is the famous fire in China in 2009 which completely devastated Beijing Television Cultural Centre. The fire started because of a wrongly conducted fireworks display. It took only 13 minutes for fire to spread throughout the entire building. And it all happened mainly due to the complete lack of fire walls in the building.

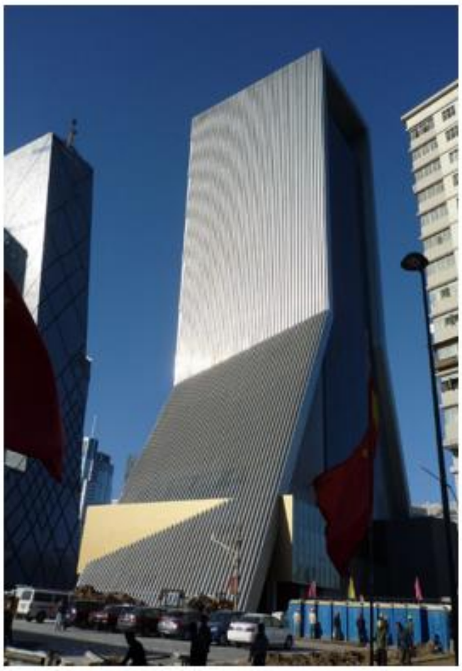 

Figure 23 - Beijing Television Cultural Center before and during the fire

Figure 24 - Beijing Television Cultural Center after the fire

3.10.2. Intumescent coatings [8]

Intumescent coating looks like a typical paint. However, in a fire situation, when large amounts of heat are generated the chemical compounds present in the coating respond to it and a chemical reaction starts. As a result, the coating begins to expand effectively tucking an element covered in the coating and forming a barrier which looks like a growth. That barrier protects the element under the coating from devastating power of heat which could cause the element to break or melt and that could lead to a structural failure and the building could even collapse.

Figure 25 - Covering a steel element in intumescent coating

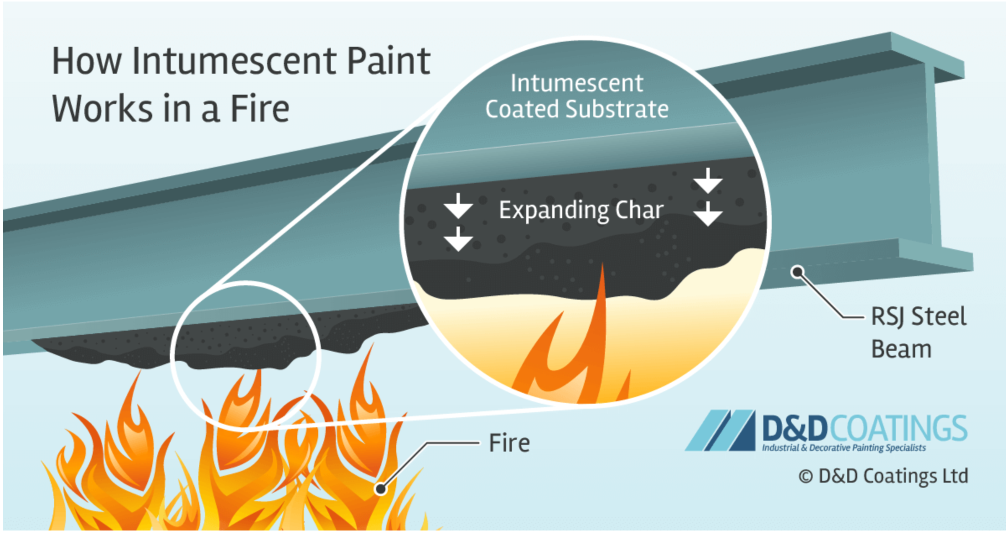

Figure 26 - Intumescent paint in a fire situation

3.10.3. Boarding systems [8]

Boarding systems act similarly to using intumescent coatings. They are used to cover fragile elements (mostly steelwork) in rigid or semi-rigid boards made of non-flammable materials in order to insulate them from harmful influence of fire and also to stiffen them in case the heat weakens their structural integrity. Boarding systems also include using fire walls to create safe compartments to limit spreading capabilities of fire and protect rooms which are not yet engulfed in flames. Fireproof panels can be used in two completely different and opposite ways. They may either dam a fire within a specially designed space effectively stopping it from fanning out or provide a means of safe egress for staff into which a fire cannot readily penetrate. The first idea is known as compartmentation and the latter is often called a protected corridor.

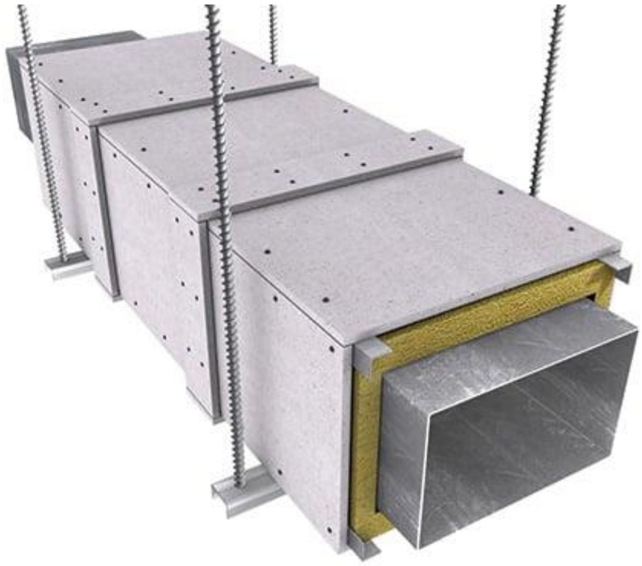

Figure 27 - A ventilation duct covered in fireproof boards

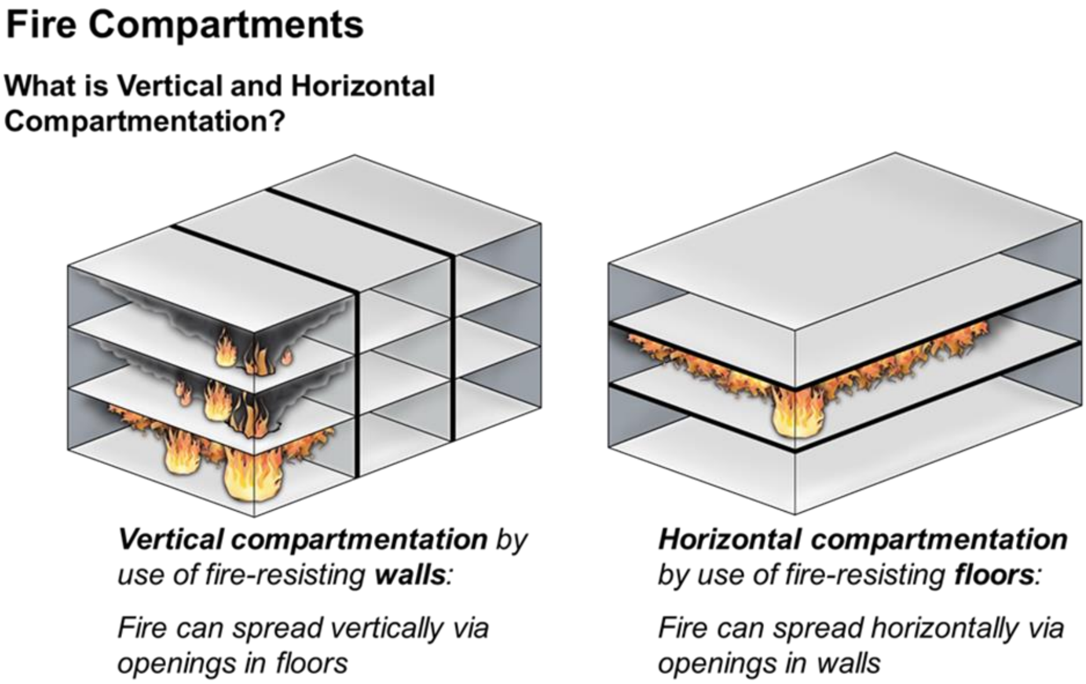

Figure 28 - An example of compartmentation

3.10.4. Fire-resistant glass [8]

Fire-resistant glass (also known as fire rated glass) is special type of glass that has been tested in terms of fire resistance during a Fire Resistance Test and has proved to withstand the fire for the required amount of time. The degree of offered protection depends on the type of fire rated glass but generally all kinds of fire-resistant glass are a good enough barrier for preventing the spread of flames and smoke in the event of a fire. Certain types of fire rated glass will also provide a degree of protection (insulation) against the heat of a fire. Ergo, fire rated glass is a crucial element in safety of buildings, so Building Regulations say exactly where it must be used.

One of the types of fire-resistant glass is gel-filled one which behaves very similarly to intumescent coatings. The glass consists of two layers of tempered glass which are separated by a layer of special gel. When the first layer of glass breaks, the gel is exposed to high heat which causes it to crystallise, creating a barrier which protects the other layer. It is very important because then there is no way for fire or smoke to travel further. Even if such gel is not used, glass still can be made sturdier. For example, by adding more layers of glass and separating them with some incombustible polymeric composites.

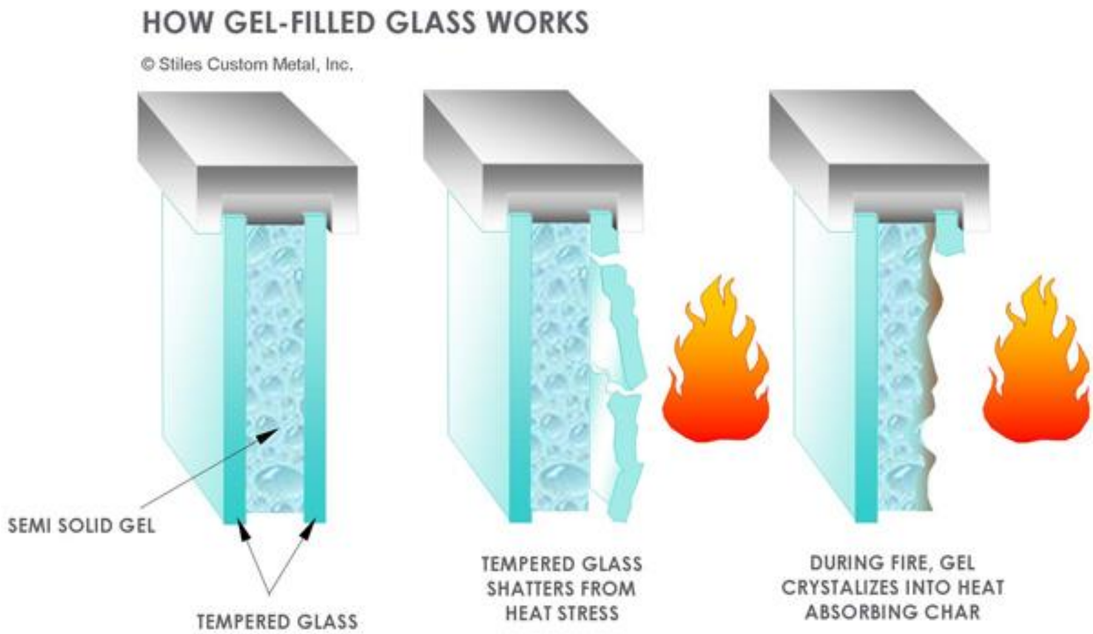

Figure 29 - Gel-filled glass exposed to fire

Two more reasons why fire rated glass is of utmost importance. The first one: the more durable it is, the less a chance that it will blow out which can be seriously dangerous if people are standing close to a window that is made of not resistant enough glass. The second one: it is common knowledge that in case of fire, if it is possible, all the windows should be closed before evacuating. This is done in order to limit the amount of oxygen in a building as much as it can be done so that the fire cannot be easily fanned and at least one of three key components which the fire needs to start and then to grow. But all of that will be in vain if the fire is able to penetrate through the windows.

Below are presented a couple of other solutions widely used as means of passive fire protection.

3.10.5. Fire doors [5]

According to the definition: "*A fire door is a door with a fire-resistance rating used as part of a passive fire protection system to reduce the spread of fire and smoke between separate compartments of a structure and to enable safe egress from a building or structure or ship.*" Both the door frame and its leaf must meet the guidelines of the testing agency providing the product listing. The door frame can have several fire protection elements. Those include the fire or smoke seals, door hardware, and the structure that holds the fire door assembly in place. Ridges of a fire door are usually required to have fire rated seals which can be composed of an intumescent strip expanding when exposed to high heat.

The majority of fire doors are meant to be kept shut at all times. Some doors are designed to stay open, but automatically close when a fire alarm is risen. No matter which type of door is used, the door's movement should never be limited by a doorstop or any other obstacle. The smoke seals as well as the intumescent bounding of fire doors should be routinely checked by an expert. It is also imperative to check whether the door still function properly. That involves examining the hinges and catches.

Figure 30 - An example of a fire door

3.10.6. Fire dampers [5]

Fire dampers are passive fire protection products installed in different types of ducts. They can be fitted in heating, ventilation, and air conditioning ducts to preclude the fire and smoke from travelling through the ductwork. Fire dampers are mainly installed in the places where a duct meets a fire wall or floor. Because a fire wall must have some holes in it (e.g. for the ducts to go through), fire dampers are a great means of nullifying that flaw.

How do they work? It is simple. Whenever a rise in temperature occurs, the damper closes its blades. That can happen in a few different ways, but the two most popular are mechanical and electronic. In the mechanical approach a thermal element present in a fire damper melts at certain temperatures, which causes springs to move and close the damper. In the electronic method an electrical signal is generated whenever a fire alarm goes off and that signal causes a small servomotor in the damper to shut its blades.

Figure 31 - Fire dampers (open and closed)

3.10.7. Smoke dampers [5]

Smoke dampers are also commonly used in buildings as it exhausts smoke from an area while pressurizing the smoke-free areas around the affected area. When the temperature exceeds 74°C (165°F), the fusible link melts and the damper closes like a curtain and locks. It is considered as a passive fire protection product as it can be utilised in compartmentalisation of buildings and suppresses the spread of smoke. Smoke dampers are installed in air conditioning, ventilation ductwork or physical smoke barriers. The difference between a smoke damper and fire damper is that a smoke damper is a damper arranged to seal off airflow automatically through a part of an air duct system so as to restrict the passage of smoke whereas a fire damper is an automatic-closing metal assembly of one or more louvers, blades, slats or vanes that close upon detection of heat so as to restrict the passage of flame. In LabFactor, there are smoke dampers in the atrium and staircases.

Figure 32 - A smoke damper

3.10.8. Intumescent dampers [9]

Intumescent dampers are a special kind of fire dampers. They are nothing like the previous dampers so there is no mechanical system that closes it. Instead, intumescent dampers have a lattice made of intumescent material. In the event of a fire lots of heat is generated and that starts a chemical reaction. The lattice expands and swells which decreases the hole diameter and after a while the damper becomes airtight and neither smoke nor fire can easily penetrate through it.

Figure 33 - An intumescent damper

3.10.9. Spray Applied Fireproofing [10]

The technical name for Spray Applied Fireproofing is Sprayed Fire-Resistive Material (SFRM). It is used as part of a building's passive fireproofing strategy. SAF is the most potent in insulating steelwork from the high temperatures in the event of a fire.

Sprayed Fire-Resistive Material is composed of cement or gypsum and often contains other materials like mineral wool, quartz, perlite, or vermiculite. The gypsum or cement makes up the majority of the solution and is selected because it hardens as it dries. The other materials are used to help lighten the solution or to add air as in insulator. Chemical hardeners are sometimes used to either speed up hardening or to make the final fireproofing harder than normal.

Figure 34 - A worker applying a special fire-resistant mixture on steel elements

Figure 35 - Steel elements covered in a fire-resistant mixture

With so many passive fire protection solutions present the question whether active fire protection is really necessary arises. In the event of a fire, active fire protection systems will initiate. They will do two things: raise the alarm - which is a sign for people inside to start evacuation - and also systems like sprinklers will activate.

Passive fire protection is not about fighting the fire but rather trying to slow down its growth and limit its destructive capabilities. By compartmentalising the building and removing smoke, PFP systems give occupants more time to egress and prevent widespread damage to the building before emergency services arrive. That proves the fact that both passive and active fire protection systems are of utmost importance.

The value of lives, property and assets can be incalculable. When the fire is contained early - people will have time to evacuate and normal business will be back working much sooner. Taking care of installing passive fire protection systems is the least that can be done in order to prevent catastrophes, disasters and - what is the most important thing - people from dying.

3.11. ACTIVE FIRE PROTECTION SYSTEMS [5]

Active fire protection is one of the most important elements to consider and plan for when building any type of modern structure. Recent decades have seen considerable developments in the area of active fire protection, with systems becoming more sensitive and equipped with state-of-the-art technology, ensuring maximum efficiency. Over the years, this has resulted in the decreasing number of serious indoor fire-related incidents across the world, providing a safer and more protected environment for modern citizens to live, work and shop in. People normally think of fire protection in two forms – alarms and sprinkler systems. But, Active Fire Protection (AFP) is really much broader – these systems work to detect, alert, control and suppress or extinguish a fire.

Active fire protection is the process of protecting a building or structure from fire with methods that use the action of moving parts. These systems may be manually operated, like a fire extinguisher or automatically, like a sprinkler, but either way they require some amount of action. Fire/smoke alarm systems are used to detect whether there is fire and/or smoke in a building. Sprinkler systems are used to help slow the growth of the fire. Fire extinguishers and firefighters are used to help put out the fire altogether.

Active fire protection refers to systems that involve a triggered response to a fire. Active systems are initiated by the flame -and the response may be manual (for example, a hand operated fire extinguisher qualifies as an active response) or programmed (for example, a sprinkler system).

These systems are considered to be a proactive approach to extinguishing fires and controlling the spread of smoke.

These measures are typically divided into two categories: *fire detection* and *fire suppression*. As the names give away, one of these categories relates to measures destined to point out that a fire has broken out, while the other deals with measures meant to ensure it is extinguished quickly and efficiently.

One additional measure, which cannot be considered to fit within either of these categories, is oxygen reduction. Oxygen reduction systems are commonly known as *hypoxic air systems* and are usually put into place as a preventive measure, rather than to detect or suppress a fire.

3.11.1. Control Panels [11]

The fire-detection system today comprises of a fire alarm control panel (FACP) presented on the image below. This is the system's brain and it is capable of making rapid decisions. Detection devices run in numerous aspects, from smoke detectors and heat detectors to multi-capability detectors, which contain a number of functions in one detector. Many of the detectors manufactured today have addressable switches contained in the detector that allow the detector to tell the FACP exactly where the fire is located. The detection devices detect the presence of smoke or particles of combustion and then alert the FACP about a problem. In such case, the FACP decides what action to take.

The LabFactor building has one main FACP to manage all rooms and corridors. This control panel is not automated. The operation of the panel assumes that there will be a person who is authorized to use it. Whenever the fire breaks out - the smoke detectors are triggered - the information appears on the panel. Then the authorized person has a few minutes to check what happened and then through the panel cancel the alarm or call the fire brigade.

Figure 36 - Fire alarm control panel

3.11.2. Fire Detectors [11]

Formerly, humans were excellent fire detectors. The healthy person is able to detect numerous factors of fires including heat, flames, smoke, and odours. Hence, most fire alarm systems are designed with one or more manual alarm activation devices to be used by anyone who discovers fires. Unfortunately, a person can also be an unreliable detection method since they may not be present when fires start, may not raise an alarm in an effective manner, or may not be in perfect heath to recognize fire signatures. What results in developing a variety of automatic fire detectors? Automatic detectors are intended to imitate one or more of the human senses of touch, smell or sight. Thermal detectors are similar to our ability to identify high temperatures, smoke detectors replicate the sense of smell, and flame detectors are electronic eyes. The properly selected and installed automatic detector can be a highly reliable fire sensor.

The LabFactor has only the smoke detectors which are quite sensible. That means, that they can be triggered by wisp of smoke.

Figure 37 - A thermal detector (left) and a smoke detector (right)

3.11.3. Alarm Output Devices [11]

Upon receiving an alarm notification, the fire alarm control panel must tell someone that an emergency is underway. This is the primary function of the alarm output aspect of a system. Occupant signalling components include various audible and visual alerting components, and are the primary alarm output devices. Bells are the most common and familiar alarm sounding device and are appropriate for most building applications. Horns are another option and are especially well suited to areas where a loud signal is needed, such as library stacks, and architecturally sensitive buildings where devices need partial concealment. Chimes may be used where a soft alarm tone is preferred, such as health care facilities and theatres. Speakers are the fourth alarm sounding option, which sound a reproducible signal such as a recorded voice message. They are often ideally suited for large buildings where phased evacuation is preferred. Speakers also offer the added flexibility of emergency public address announcements. With respect to visual alert, there are a number of strobe and flashing light devices. Visual alerting is required in spaces where ambient noise levels are high enough to preclude hearing sounding equipment, and where hearing-impaired occupants may be found.

Figure 38 - Types of alarm devices

In the LabFactor there are the horns and the extraordinary speakers. The horns are launched when smoke detectors will be triggered.

3.11.4. Fire suppression [11]

Fire can be controlled or extinguished, either manually (firefighting) or automatically. Manual control includes the use of a fire extinguisher or a standpipe system. Automatic control means can include a fire sprinkler system, a non-toxic gaseous clean agent, or preventive foam system.

In the LabFactor there no active fire suppression systems except of manual fire extinguishers.

3.12. NATURAL VENTILATION SYSTEMS [12]

Smoke is one of the most dangerous factors involved in the spread of fire. While protecting from the damage of fire and endeavouring to nullify it is of utmost importance, under no circumstances can smoke influence be neglected. Soot particles are even more pernicious to human beings than a pure fire. They can limit the visibility quite immensely making it nearly impossible to evacuate safely. Moreover, when clouds of smoke fill the air around, the amount of oxygen is noticeably reduced. That is why different approaches to smoke control have been developed and introduced. One of the most popular ones are natural ventilation systems which inseparably connected with the phenomenon of natural ventilation.

3.12.1. Natural ventilation [13]

According to the definition: "*Natural ventilation is the process of supplying air to and removing air from an indoor space without using mechanical systems.*" In other words, mostly physical phenomena are taken into consideration when referring to natural ventilation. External air flows to an indoor space which is a direct result of differences in atmospheric pressure. Two types of natural ventilation in buildings can occur: wind driven and buoyancy-driven ventilation. The former refers to a form ventilation arising from the different pressures created by wind around buildings and openings in them which then cause the air to flow through the buildings. The latter is strictly connected with temperature differences between the inside and the outside of a building, which create the directional buoyancy force.

Figure 39 - An example of air flowing to and out of a building

3.12.2. Natural smoke ventilation [13]

Even though there is a word "natural" there, it does not mean that the systems exploiting that solution have nothing to do with automation and electricity. Natural smoke ventilation systems are all about using natural forces and physical phenomena to channel clouds of smoke outside the building. To be more specific, they use the aforementioned phenomenon of natural air flow dynamics.

In case of smoke having been detected, servomotors installed in various movable elements in the building receive electrical signals causing windows and vents to open which then allows the generated smoke to be removed. By utilising windows/vents, automatic opening vents (AOV) or, where there is no external wall, a vertical smoke shaft, a natural system uses the wind and thermal buoyancy to remove smoke. One of the main benefits of a natural system is its simplicity. The limited components required for this system makes it the cheaper smoke venting solution, as well as limiting its noise pollution, removing the requirement for acoustic silencers and keeping overall costs to a minimum.

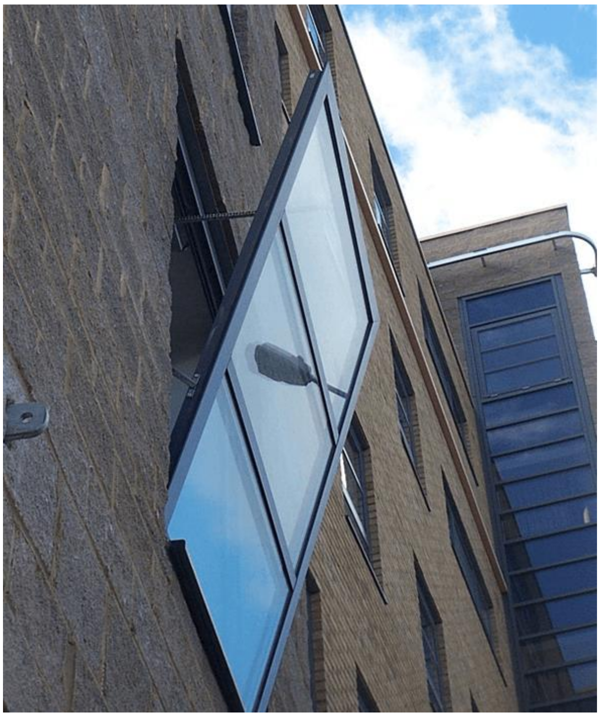

Figure 40 - An example of an automatically opened window

Figure 41 - A servomotor of an automatically opened window

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Atrium plays a special role in fire protection. It has been considered to have a great potential for enhancing natural ventilation and reducing energy use. However, during fire, due to the overall connectivity of atriums, hazards like soot particle and carbon monoxide will spread to upper storeys quickly. Hence, smoke extraction systems become one of the most pressing issues in fire protection engineering of huge buildings with atriums. Atriums may be effective in removing smoke from other rooms and floors but are also quite dangerous because they tend to expose all the occupants to the same environment and the same threats. A fire beginning in a large atrium has the potential to endanger not only those people in direct proximity to the fire, but also those many storeys above.

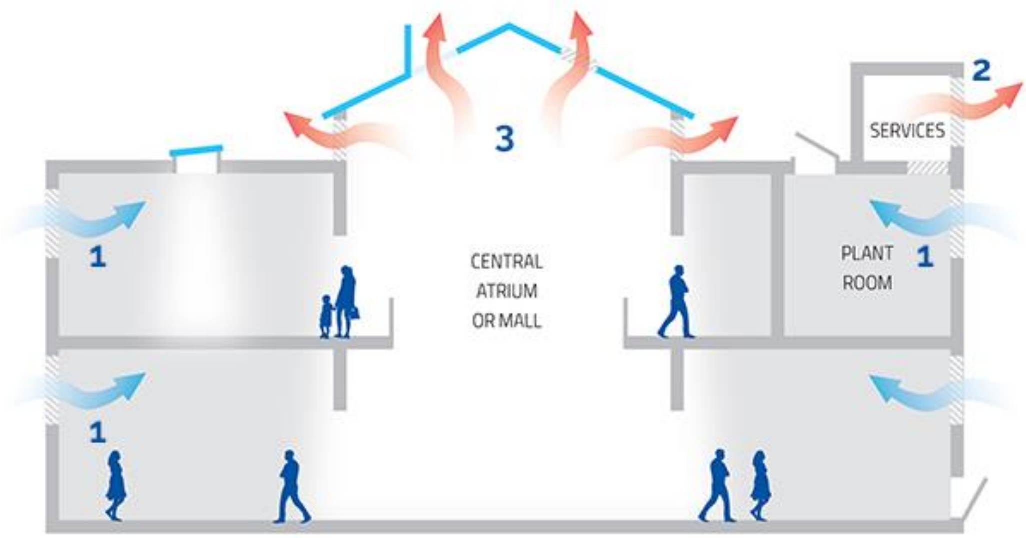

Figure 42 - Natural air flow in an atrium

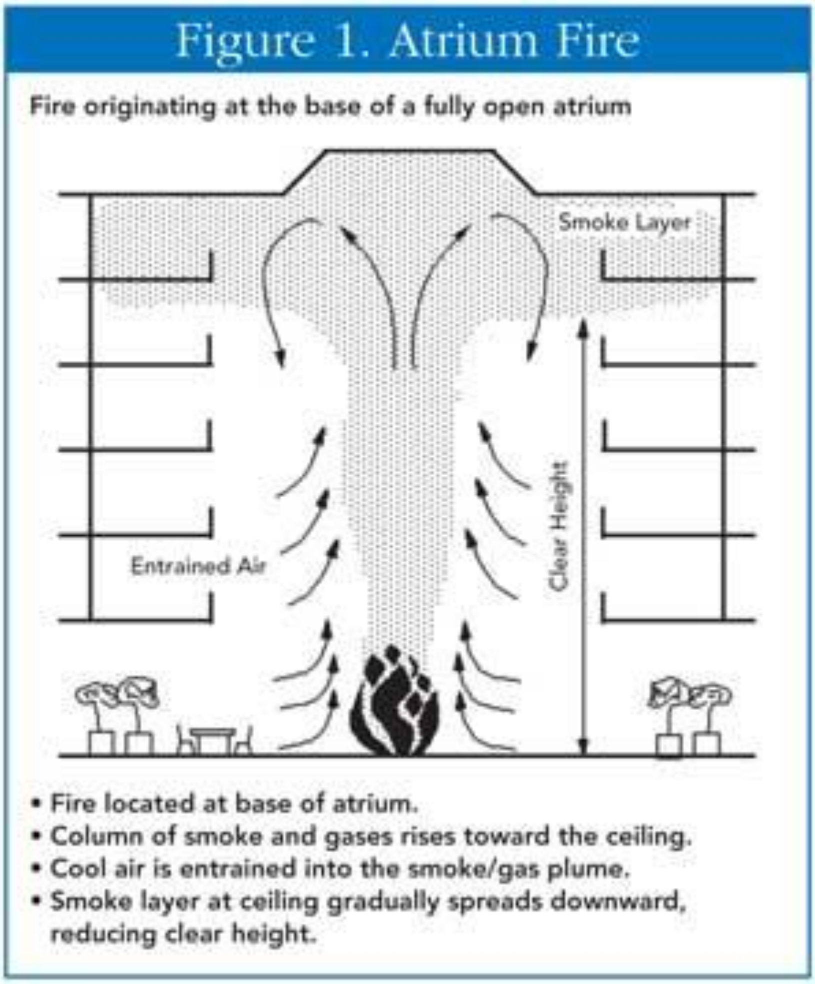

Figure 43 - Air flow in an atrium during a fire

3.13. MECHANICAL VENTILATION SYSTEMS [14][15][16]

Figure 44 - Automatically opened windows and mechanical smoke exhaust fans

The two images shown above show examples of a smoke ventilation system, such as an electronically-operated automatic window system (natural smoke ventilation), and mechanical smoke exhaust fans (mechanical smoke ventilation).

Mechanical ventilation systems aid the safe escape of occupants and allow adequate access for firefighters. It mainly comprises of a mechanical extract shaft that serves the common corridor, lobby or/and atrium. The fan at the top of the mechanical smoke shaft extracts the smoke and prevents migration of smoke into the adjacent compartments. LabFactor possesses both natural smoke ventilation and mechanical smoke ventilation in the form of automatic windows n the ceiling of the atrium and a mechanical exhaust fan.

4. LABFACTOR BUILDING

Built in 2016, LabFactor is the newest building on the Lodz University of Technology campus. With more than 4000 m^2, it consists of 3 storeys and a basement. The main characteristic of the building is its atrium inside. Atrium is, basically, a big open space inside a building. This type of design has a big aesthetic component. However, when it comes to fire safety, it is extremely dangerous as it will be explained later in this report.

Figure 45 - LabFactor building

Figure 46 - LabFactor's atrium

LabFactor possesses a variety of laboratories, one of them being a smoke laboratory. This specific element makes LabFactor even a more interesting building to study, as some equipment for experiments may be borrowed from there.

It has also two elevators, two emergency staircases and the cloakroom.

Understanding the building from a technical point of view requires certain technical drawings: the building plans. However, for this specific project, drawings are not enough. Fire safety elements have to be represented as their existence (or not) on every floor has an impact on the final fire strategy evaluation.

The next drawings have been made after recognizing LabFactor's interior floor by floor.

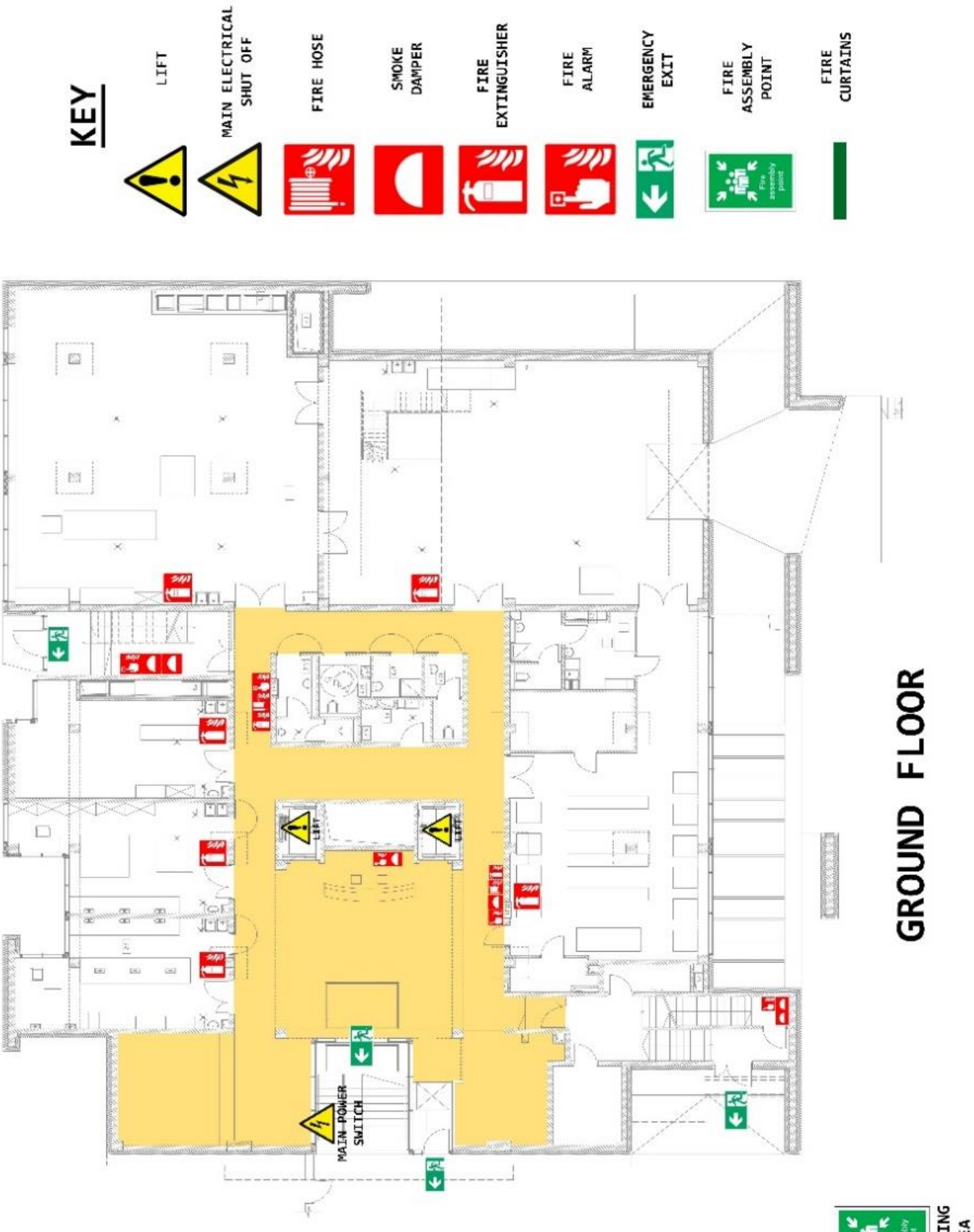

Figure 47 - LabFactor's ground floor

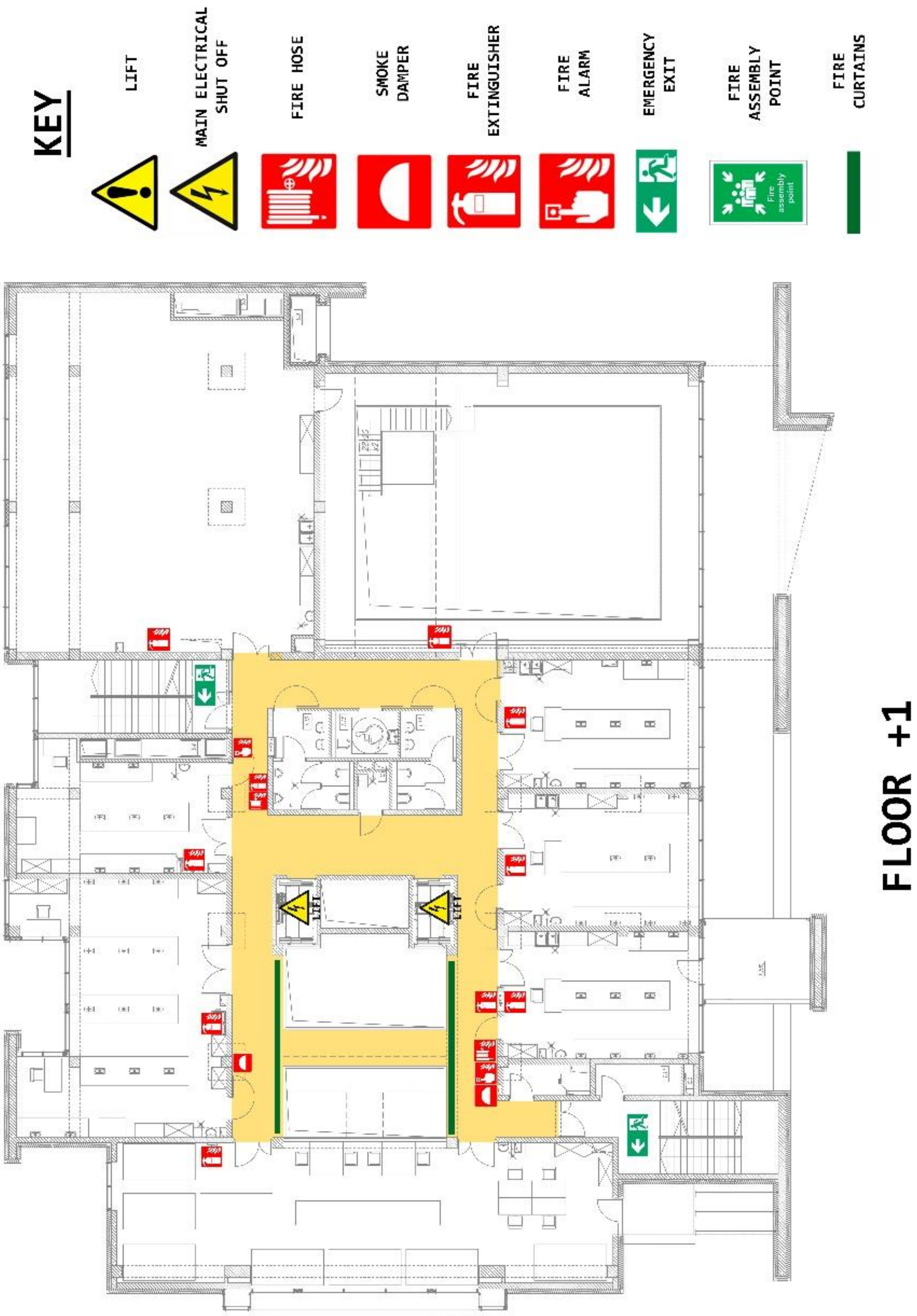

Figure 48 - LabFactor's first floor

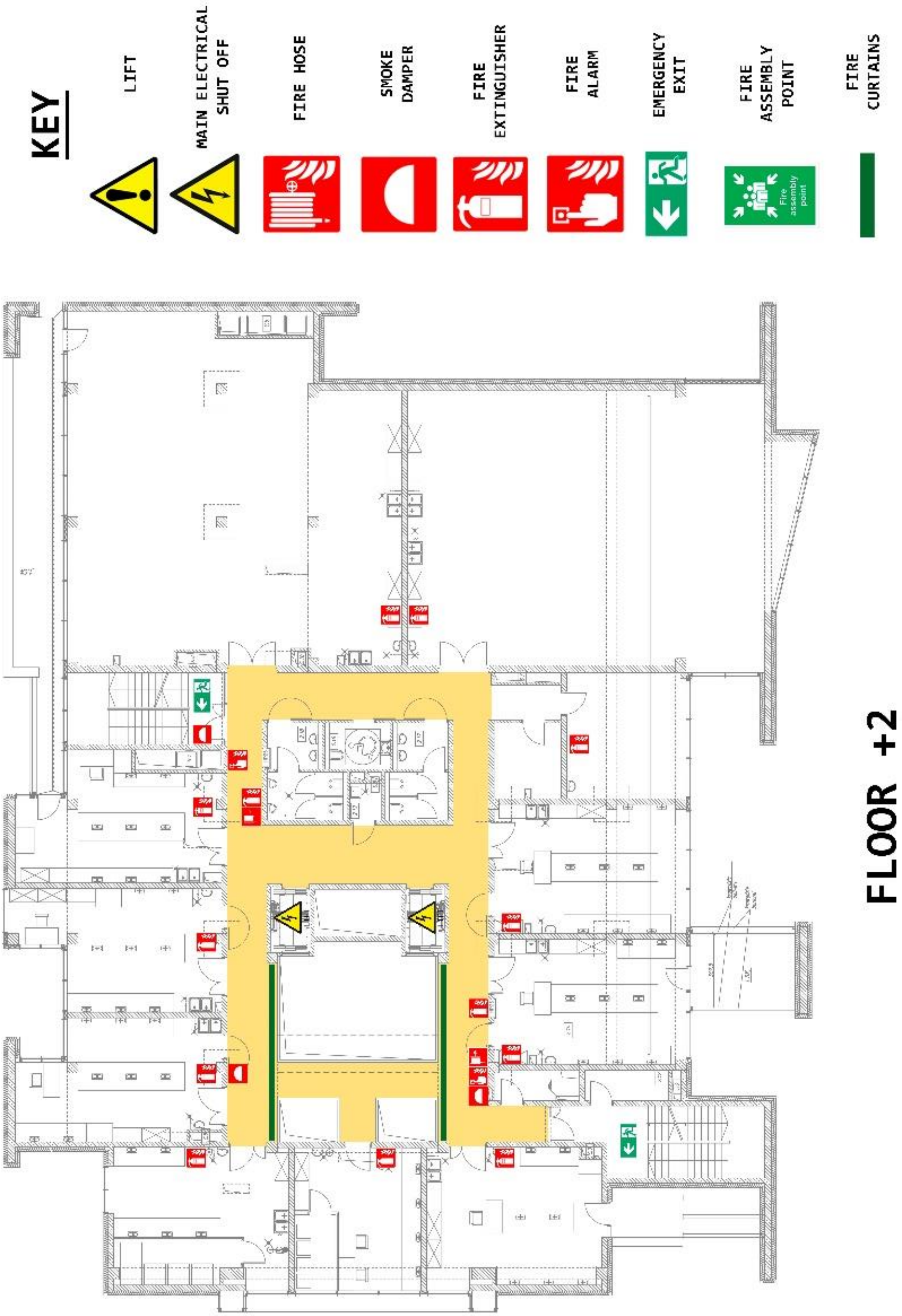

Figure 49 - LabFactor's second floor

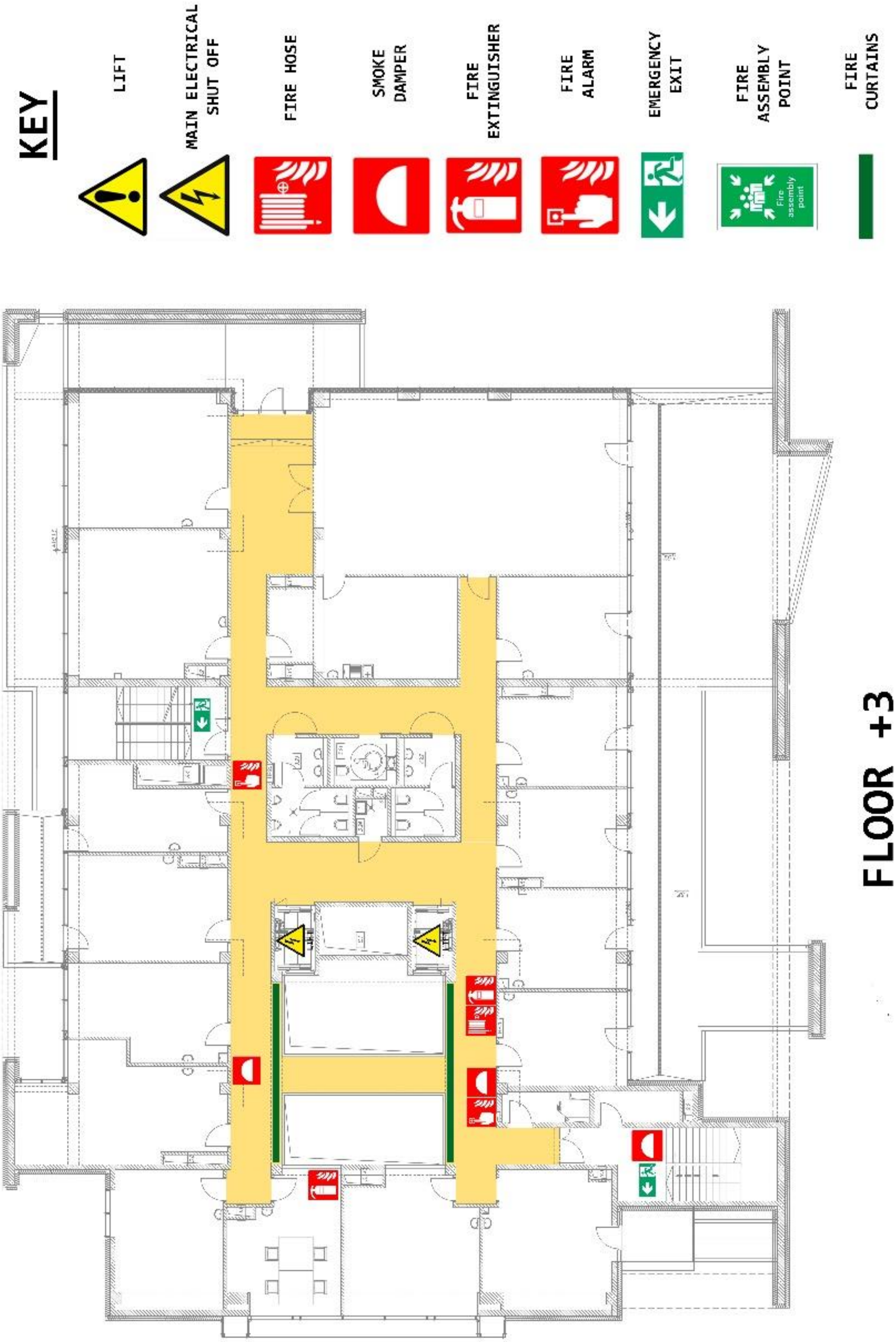

Figure 50 - LabFactor's third floor

5. EVALUATION OF LABFACTOR FIRE STRATEGY

5.1. FIRE STRATEGY EVALUATION CHART [1]

Fire strategies are an innovative way of evaluating buildings in terms of fire safety. They cover most important aspects that should be taken into consideration while assessing whether a building is up to a certain standard.

The evaluation process can be shown as a simple algorithm which steps are as follows:

1. Define a fire strategy **key objective**.
2. Choose building **risk profile**.
3. Create a **baseline fire strategy** for the risk profile.
4. Score an **actual fire strategy** - fire safety factors of the building.
5. Present the results in the form of a **fire strategy value grid**.
6. Calculate Fire Risk Indices for the baseline strategy (**FRI_{BAS}**) and the actual one (**FRI_{AC}**).
7. If $FRI_{BAS} > FRI_{AC}$, the actual fire strategy is accepted.
8. If $FRI_{BAS} \leq FRI_{AC}$, the actual fire strategy is not acceptable, it should be changed and every point starting from the fourth one should be revisited.

The key objectives are presented on the graph below. They show the aims of a fire strategy that will be taken into consideration.

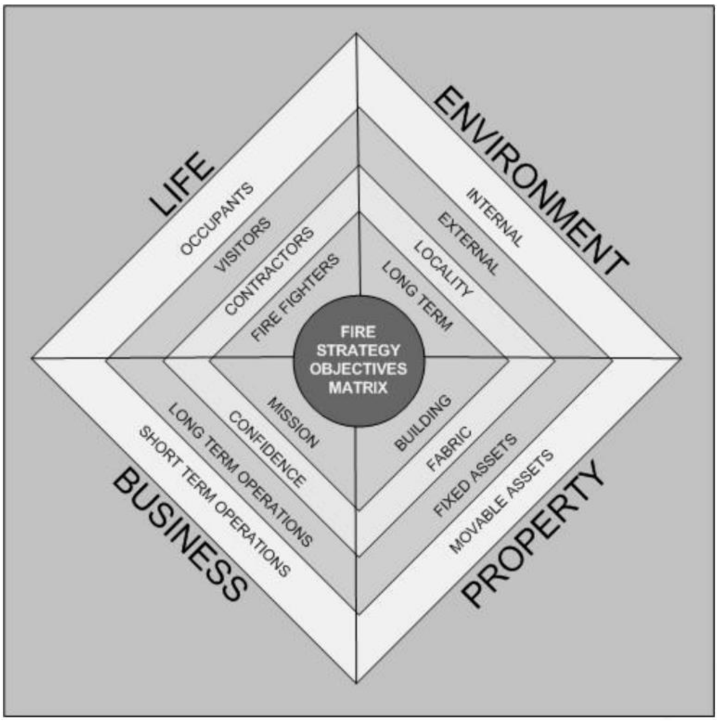

Figure 51 - Fire strategy objectives matrix

For the LabFactor building, it was decided that life safety of people was the most important objective of the fire strategy. The risk profile at the building was assumed to be B2, in accordance to the risk profiles description in [1]. The B2 risk profile was used for the baseline fire strategy, used for actual LabFactor fire strategy evaluation.

The fire strategy evaluation is based on the scoring of eight main fire safety factors, in the scale from 0 to 25, in accordance to the table below:

Layer of fire protection	Fire safety factor (FSF)	Symbol	Score
Fire prevention and fire spread limitation	1. Organisation and Management	**ORG**	0 - 25
	2. Control of ignition sources and combustible materials	**LIM**	0 - 25
Fire protection measures	3. Fire and smoke spread limitation - passive systems	**PAS**	0 - 25
	4. Detection and alarm communication	**DET**	0 - 25
	5. Fire suppression	**SUP**	0 - 25
	6. Smoke control and evacuation	**SC**	0 - 25
	7. Maintenance of fire precautions and systems	**MAI**	0 - 25
Fire fighting	8. Fire services intervention	**FB**	0 - 25

Table 2 - Fire safety scoring system

As mentioned before, LabFactor was considered to be a school building of risk profile B2 and its baseline strategy was provided by experts in the field of fire engineering.

Scoring the actual fire strategy is shown on forms below covering all of the aforementioned fire safety factors. It was performed specifically for the LabFactor building with the assumption that the key objective is life and the risk profile, as mentioned above, is B2.

Although LabFactor features smoke curtains, they are only part of the Laboratory of Smoke. That means that in case of fire they will not be automatically activated and for this reason they will not be considered under the *Smoke control and evacuation* factor (see table 8). [1]

Fire safety factor (FSF)	Fire strategy evaluation form			
	Fire safety element		Maximum score	Actual score
1. Organisation and Management [ORG]	**1**	Fire strategy: not developed (0) / has been developed for selected aspects (1) / has been developed and documented in all aspects necessary for the predefined strategy objectives (4)	4	4
	2	Documented fire safety procedures for the building (1) + implementation of the procedures (1) + regularly controlled updates (1) + documented evacuation plans for all floors (1)	4	2
	3	Central building security personnel for the building (1) + trained fire wardens on all floors/in zones (3) + regular evacuation drills with specific staff participation (2) / regular evacuation drills involving all building occupants (3)	7	1
	4	Fire safety training: only key staff (2) / all staff (4)	4	2
	5	Independent certification and audit system for fire safety management: only mandatory checks (1) + full regular fire safety audits, undertaken by specialist bodies (1)	2	1
	6	Management commitment to fire safety including fire safety management review meetings and training of personnel in the key aspects of the management, operation and maintenance of fire protection systems, and the principles of fire strategy, evacuation strategy awareness, etc. (0 to 4)	4	0
		Total	**25**	**10**

Table 3 - Organisation and Management scoring table

Fire safety factor (FSF)	Fire strategy evaluation form			
		Fire safety element	**Maximum score**	**Actual score**
2. Control of ignition sources and combustible materials [LIM]	**1**	Fire load density [MJ/m2] (>4000) (0) / (>2000, ≤4000) (1) / (>1000, ≤2000) (2) / (>500, ≤1000) (4) / (≤ 500) (5) + High hazard ignition sources Y (0) / N (2)	7	7
	2	Expected fire growth: ultrafast (0), fast (1), medium (4), slow (5)	5	4
	3	High risk areas of the building are separated from other parts of the building by suitable fire resisting construction Y (2) / N (0) + high levels of combustible materials stored in the building - Y (0) / N (2)	4	4
	4	Smoke production from construction products and fixed equipment (the worst case): s3 and products of reaction to fire class ≤E (0) / s2 (1) / s1 and products of reaction to fire class A1 (2)	2	1
	5	Reaction to fire class of construction products (claddings/coverings) (the worst case) ≤E (0) / D i C (1) / B (2) ≥A2 (3)	3	2
	6	Reaction to fire class of the building insulation products (external walls, roof) (the worst case): ≤E (0) / D i C (1) / B (2) ≥A2 (4)	4	2
		Total	**25**	**20**

Table 4 - Control of ignition sources and combustible materials scoring table

Fire safety factor (FSF)	Fire strategy evaluation form			
		Fire safety element	Maximum score	Actual score
3. Fire and smoke spread limitation - passive systems [PAS]	1	Fire resistance of structural elements: <15 min (0), 15 min (1), 30 min (2), 60 min (3), 90 min (4), ≥120 min (6),	6	3
	2	Maximum fire resistance of internal subdivisions: 30 min (1), 60 min (2), 120 min (3), 240 min (4)	4	2
	3	Fire resistance of doors and shutters: No resistance rating (0) / 30 min (1), 60 min (2), 120 min (3), 240 min (4)	4	1
	4	Distance from neighbouring buildings: Not in accordance with regulations (0) / in accordance with regulations (2) / fire wall used as separation (2) / the heat flux density on adjacent object walls < 12,5 kW/m² (2)	2	2
	5	Compartmentation - fire zones [m2] (>20000) (0) / (>10000, ≤20000) (1) / (>5000, ≤10000) (2) / (>2000, ≤5000) (3) / (>1000, ≤2000) (4) / (≤1000) (5)	5	3
	6	Activation of fire shutters, doors, dampers etc. with fusible links (1), manual activation via control panel (2) / automatic after verification (3) / automatic (4)	4	3
		Total	**25**	**14**

Table 5 - Fire and smoke spread limitation - passive systems

Fire safety factor (FSF)	Fire strategy evaluation form			
		Fire safety element	Maximum score	Actual score
4. Detection and alarm communication [DET]	**1**	Full monitoring, i.e. detection in all risk areas (5) / partial monitoring (1) + detection in evacuation routes (1) / manual system (1) / no detection (0)	5	5
	2	Expected detection response time (>420 s) (0) / (>300 s, ≤ 420 s) (2) / (>180 s, ≤ 300 s) (3) / (≤180 s) (5)?	5	5
	3	All detection devices are appropriate for the risk (0 to 4)	4	4
	4	Sufficient and suitable control and indicating equipment in the building, including power supplies and cables (2) + certified systems (1)	3	3
	5	False alarms controlling procedures: No (0) / Yes (4)	4	4
	6	Alarm warning systems: sounders (1) / voice alarm (2) / Voice alarm with public address (3) + active visual support signage (1)	4	3
		Total	**25**	**24**

Table 6 - Detection and alarm communication

Fire safety factor (FSF)	Fire strategy evaluation form			
	Fire safety element		Maximum score	Actual score
5. Fire suppression [SUP]	**1**	Fire suppression systems covering all risk areas (3) / partial coverage only (2) / no suppression systems (0) + fast response sprinklers (1)	4	0
	2	Fire suppression response time index (RTI): standard B (>200, ≤ 300) (1)/ standard A (>80, ≤ 200) (2)/ special (>50, ≤ 80) (3) / fast (≤ 50) (4)?	4	0
	3	Expected activation time: (s): >300 (0)/ (>200, ≤ 300) (1) / (>150, ≤ 200) (2)/ (>120, ≤ 150) (3) / (≤ 120) (4)?	4	0
	4	Fire suppression systems appropriate to: the height of storage (2) + type of combustible material (2) + storage method (2)	6	0
	5	Reliability of suppression installation: system monitoring (1), independent power supply and water suppression systems (1) operation + dual water supply (1) + double source water supply (1)	4	0
	6	Hose reels covering all parts of the building Y (1) / N (0) + portable fire extinguishers (pfe) with rated extinguishing efficiency provided sited to standard accepted densities (1) or enhanced densities (2).	3	2
		Total	**25**	**2**

Table 7 - Fire suppression scoring table

Fire safety factor (FSF)	Fire strategy evaluation form			
	Fire safety element		Maximum score	Actual score
6. Smoke control and evacuation [SC]	**1**	Stair core smoke control: Non-existent (0) / in place but effectiveness not specified (1) / assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4	1
	2	Horizontal evacuation routes smoke control system: Non-existent (0) / in place but effectiveness not specified (1) / assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4	1
	3	Smoke enclosure control system: Non-existent (0) / in place but effectiveness not specified (1) / assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4	0
	4	Aspects of the construction of the means of escape could potentially lead to uncontrolled smoke production (0) / Suitable control of combustible materials on horizontal evacuation routes (1) + vertical evacuation routes (2)	3	3
	5	Dimensions of stair cores and horizontal evacuation routes relevant to the amount and profile of occupants (0 to 2) + at least two stair cores (2) + at least two directions of travel from each area (2).	6	4
	6	Evacuation signage: Passive signage correctly selected and arranged (1) / illuminated signage systems (2) / dynamic illuminated signage systems to control movement of occupants (4)	4	2
		Total	**25**	**11**

Table 8 - Smoke control and evacuation scoring table

Fire safety factor (FSF)	Fire strategy evaluation form			
	Fire safety element		Maximum score	Actual score
7. Maintenance of fire precautions and systems [MAI]	**1**	Has the design, installation and commissioning of fire-fighting and fire protection systems been carried out in accordance with the manufacturer's instructions and standards? Y (2) / N (0) + by certified contractors Y (2) / partly (1) / N (0)	4	3
	2	Is there a suitable inventory of fire-fighting and fire protection systems (1) + operation and maintenance information (2)?	3	3
	3	Maintenance procedures and inspections in accordance with minimum national regulations (1) + manufacturer's instructions (2) + national standards (2)?	5	5
	4	Functional testing (over and above minimum requirements) of fire-fighting and fire protection systems to ensure maximum levels of availability and reliability: Y (6) / partly (3) / N (0)?	6	3
	5	Systems used to monitor in real time the availability and reliability of fire-fighting and fire protection systems: Y (3) / partly (1) / N (0)?	3	1
	6	Modifications to fire fighting and protection system recorded (1) + monitored (1) + audited (2)	4	1
		Total	**25**	**16**

Table 9 - Maintenance of fire precautions and systems

Fire safety factor (FSF)	Fire strategy evaluation form			
		Fire safety element	**Maximum score**	**Actual score**
8. Fire services intervention [FB]	**1**	Method of communication with fire-fighters: Manual means by building user (e.g. no automatic fire detection) (0) / manual means by building user in the case of fire detection operation (1) / automatic, via alarm receiving centre with alarm confirmed by external staff (2) / automatic, via alarm receiving centre with alarm confirmed by staff on site (4).	4	4
	2	Availability of on-site fire safety personnel to assist (2) / nominal or part time availability (1) / no availability (0)	2	1
	3	Fire brigade arrival time[s] (>900) (0) / (>600, ≤900) (2) / (>300, ≤600) (4) / (≤300) (6)	6	4
	4	Access to the building: No direct access (0) / limited access to the building (1) / direct access to at least 50% or two sides of building (2) / direct access to all parts of building perimeter (3)	3	2
	5	Internal communication for fire-fighting purposes within the building: difficult (0) / easy (1) + easy access to the fire control panel (1) + graphic display showing fire locations (1) + lighting of evacuation routes suitable for firefighting effort (1) + at least 2 staircases (1) + fire-fighters lifts with lobbies (1)	6	3
	6	Fire service facilities: No firefighting facilities (0) / suitable fire-fighting hose reels or dry /wet risers on each level (2) + smoke ventilation controls available (1) + fire pump provisions on site (1)	4	3
		Total	**25**	**17**

Table 10 - Fire services intervention

The comparison of the two fire strategies is shown in the table below:

FIRE SAFETY FACTOR	BASELINE	ACTUAL
Organisation and Management	8	10
Control of ignition sources and combustible materials	19	20
Fire and smoke spread limitation - passive systems	11	14
Detection and alarm communication	7	24
Fire suppression	3	2
Smoke control and evacuation	8	11
Maintenance of fire precautions and systems	7	16
Fire services intervention	6	17

Table 11 - Comparison of the baseline and actual fire strategies for LabFactor

While presenting the scoring in the form of tables might be enough, there is actually a better, more informative way, namely - a chart. [1]

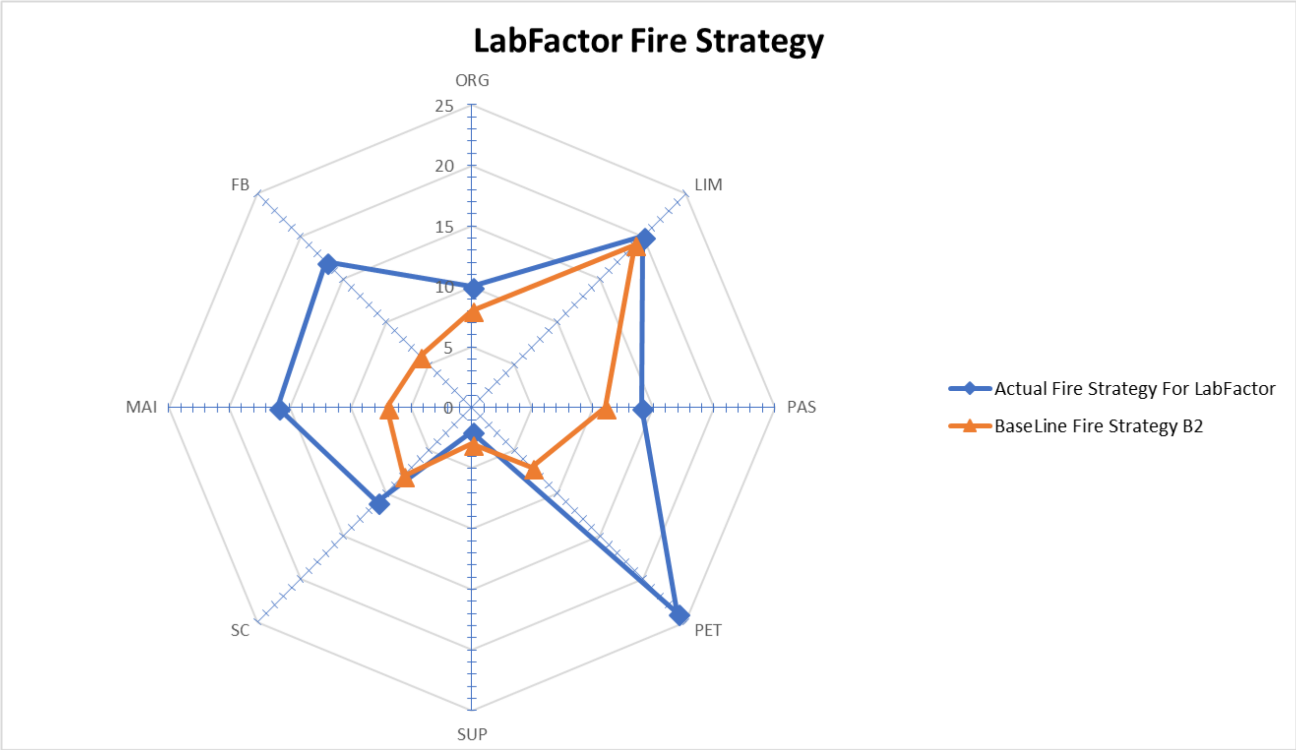

Figure 52 - LabFactor fire strategy presented in a chart

The final fire strategy evaluation based on the base of the Fire Risk Index calculation for the both Baseline and actual fire Strategies, in accordance to the methodology described in [1]. The formula for calculating the Fire Risk Index is as follows:

$$FRI = FHI * Fi$$

where FHI - Fire Hazard Index and Fi - Frequency of ignition.

Fire Hazard Index is calculated according to the formula presented below:

$$FHI = \frac{PH}{PM}$$

where PH - Potential Hazard and PM - Protective Measures.

Potential Hazard and Frequency of ignition were provided by the experts and they were equal to **1.51** and **0.108**, respectively. The weighting factors used for calculations based on the literature [1].

Protective Measures variable is equal to the sum of each score in the strategy multiplied by its corresponding weighting factor. In the case of LabFactor and its baseline strategy PMs were equal to **218** and **150.6**, respectively.

Taking into consideration all the above factors, the Fire Risk Index for LabFactor was equal to **0.0075** and was smaller than its baseline counterpart which was **0.1100**.

The results indicate that the fire strategy used in the LabFactor building is better than the base one - adopted for this type of building.

Without any doubts, the fire strategy of the LabFactor building is sufficient in relation to the concept of fire strategies and the grid value. It allows to state that the fire protection measures applied in the building provide an expected level of human life protection. Unfortunately, presented results do not take into consideration buildings with atriums and the problem of dealing with the smoke. Simulations presented below will elaborate on that problem and give proposals of possible solutions.

5.2. FIRE DYNAMICS SIMULATIONS

Although, the evaluation of the fire strategy for LabFactor shows that the building is protected enough, it was decided that Fire Dynamics Simulations should be conducted in order to check whether there are no flaws in the developed strategy. To do this, the plans of the building needed to be examined so as to determine the worst-case scenario for fires. Generally, the fire load in that very building is quite small. However, one place in the building can be dangerous in case of ignition, namely the cloakroom.

First of all, it is not a separate room, but rather a part of the same fire zone, which means that fire and smoke can easily spread to the atrium.

Secondly, in winter the cloakroom is likely to be full of clothes, which means that the probability of ignition as well as the fire load are incomparably bigger.

For the aforementioned reasons, the cloakroom was chosen to be a place where a source of fire was placed during the simulations.

If a deeper analysis is made, there are new, dangerous elements that can act as igniters: smart phones and electronic cigarettes. These elements have been proved to be able to explode and catch fire, and as they are usually saved in the pockets they can end up in the cloakroom.

In the next drawing, the cloakroom location can be seen on the top left corner of the ground floor.

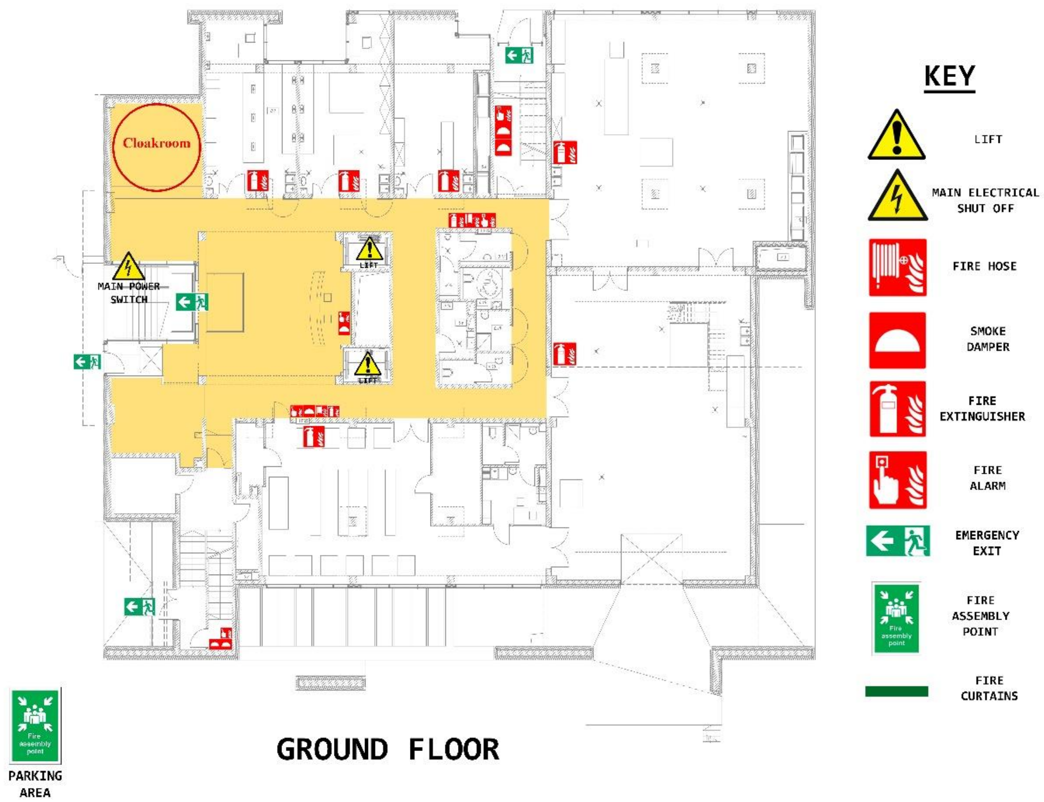

Figure 53 - LabFactor's ground floor plan with the cloakroom represented

Once the fire source location has been chosen, realistic simulations can be created.

Initially, 4 different scenarios were selected according to the safety elements installed:

1) With curtains and with natural ventilation.
2) With curtains and with mechanical ventilation.
3) Without curtains and with natural ventilation.
4) Without curtains and with mechanical ventilation.

However, after analysing the simulations, almost no difference could be seen between natural and mechanical ventilation systems. Then, only two variables were selected, using natural ventilation systems:

1) With curtains.
2) Without curtains.

1) With curtains

In order to simulate smoke behaviour, it is important to consider two main factors: how the smoke is going to behave and what is going to be the visibility in every area.

The next simulation responds to smoke behaviour in LabFactor.

Figure 54 - 3D smoke simulation with curtains at 60+ seconds

Figure 55 - 3D smoke simulation with curtains at 100+ seconds

Figure 56 - 3D smoke simulation with curtains at 150 seconds

It can be observed how the curtains stop most of the smoke from entering into the corridors, keeping practically all the smoke volume within the atrium.

Ground floor, as it does not have these safety elements, has more smoke in the corridors.

Figure 57 - 3D smoke simulation with curtains at 900 seconds

Down below is the visibility simulation.

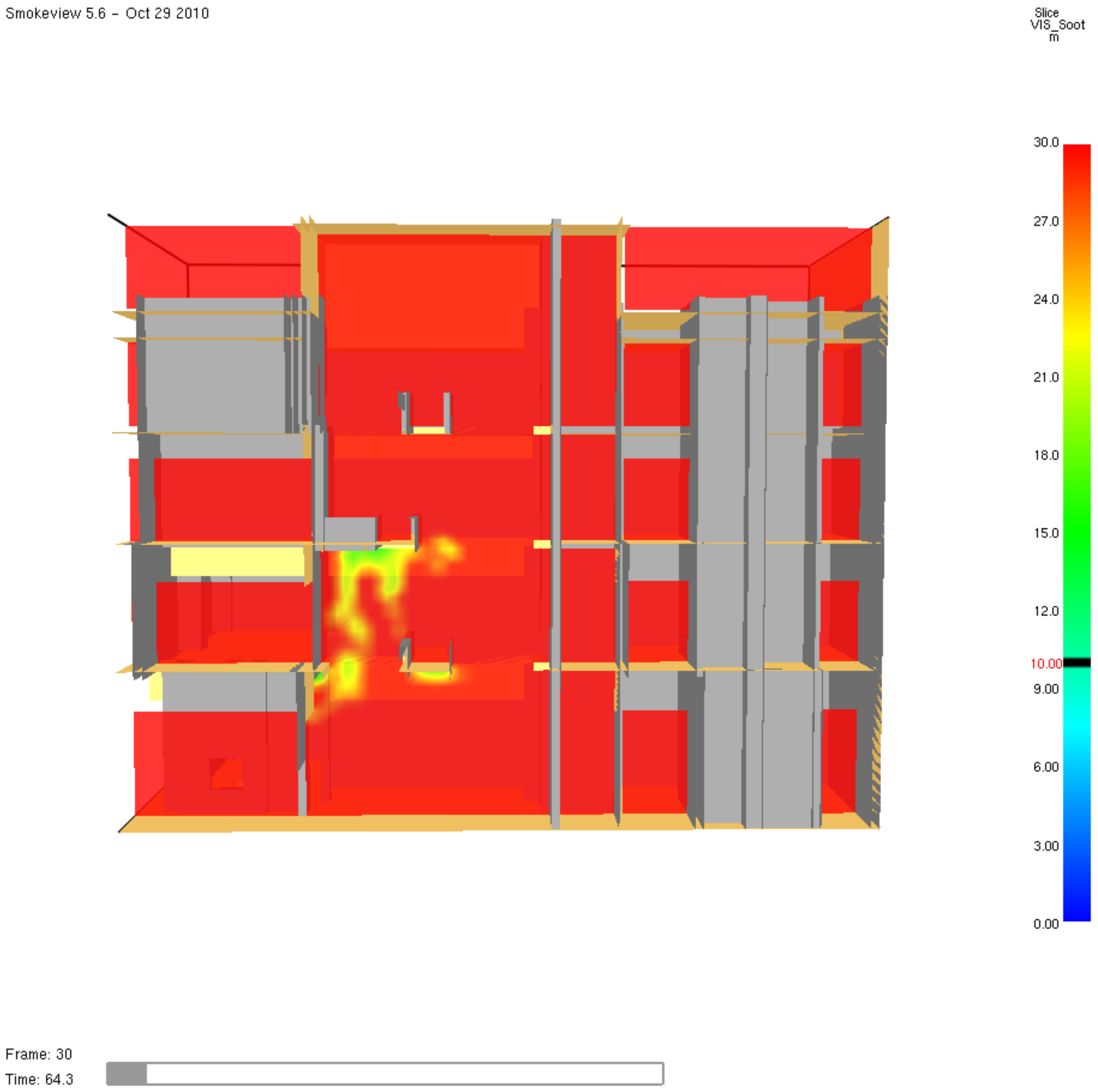

Figure 58 – Visibility simulation with curtains at 60+ seconds

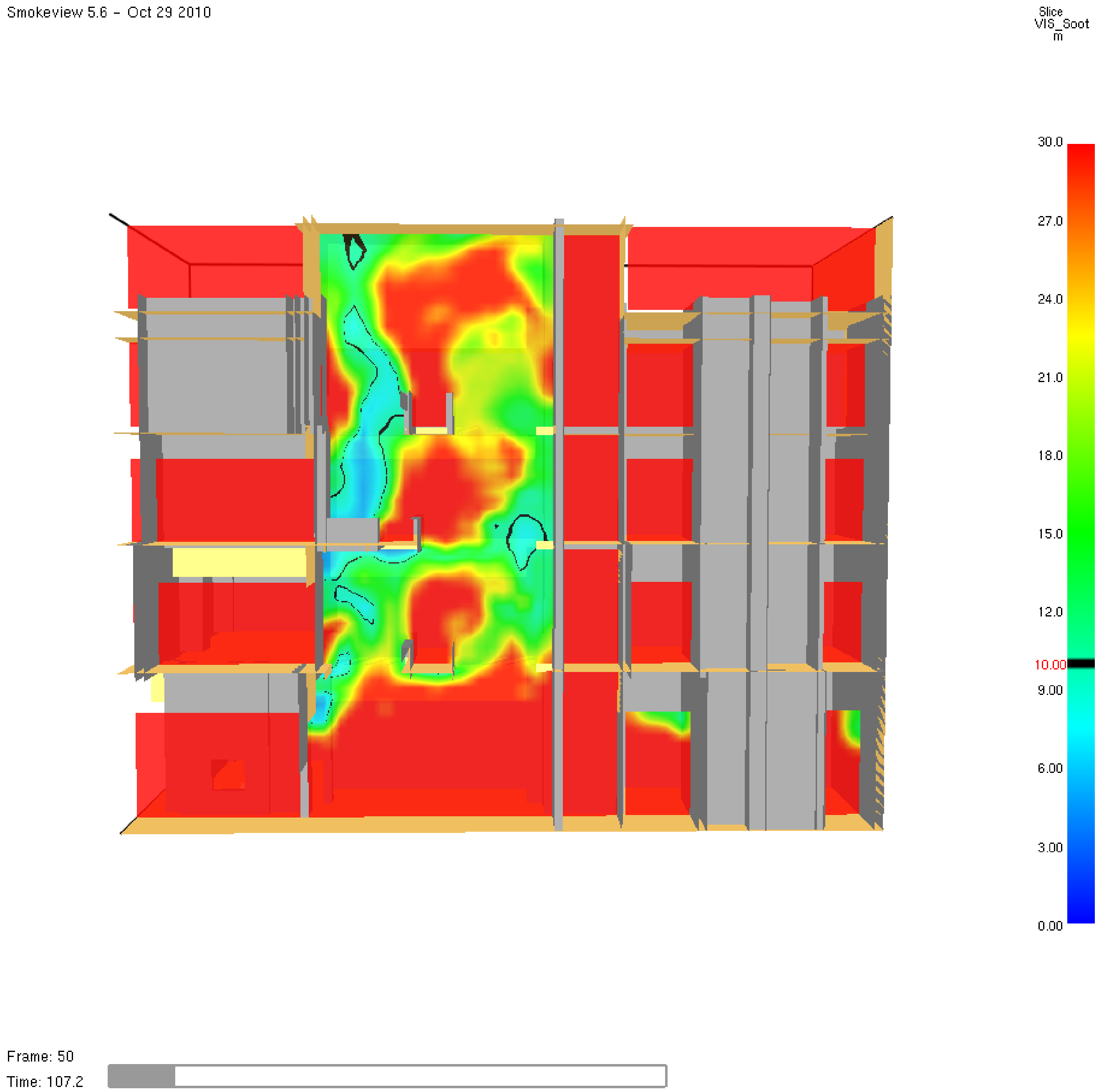

Figure 59 - Visibility simulation with curtains at 100+ seconds

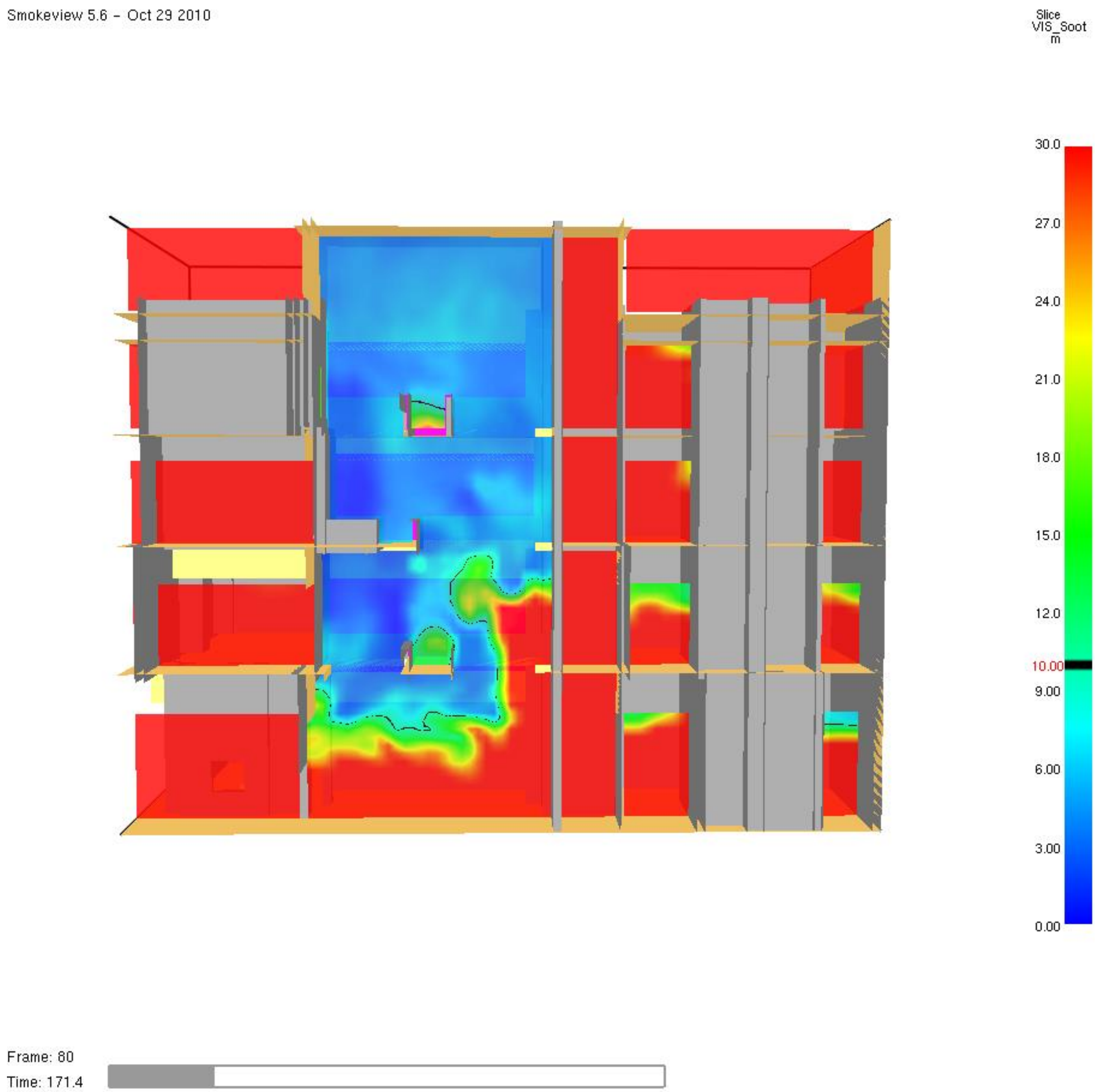

Figure 60 - Visibility simulation with curtains at 170+ seconds

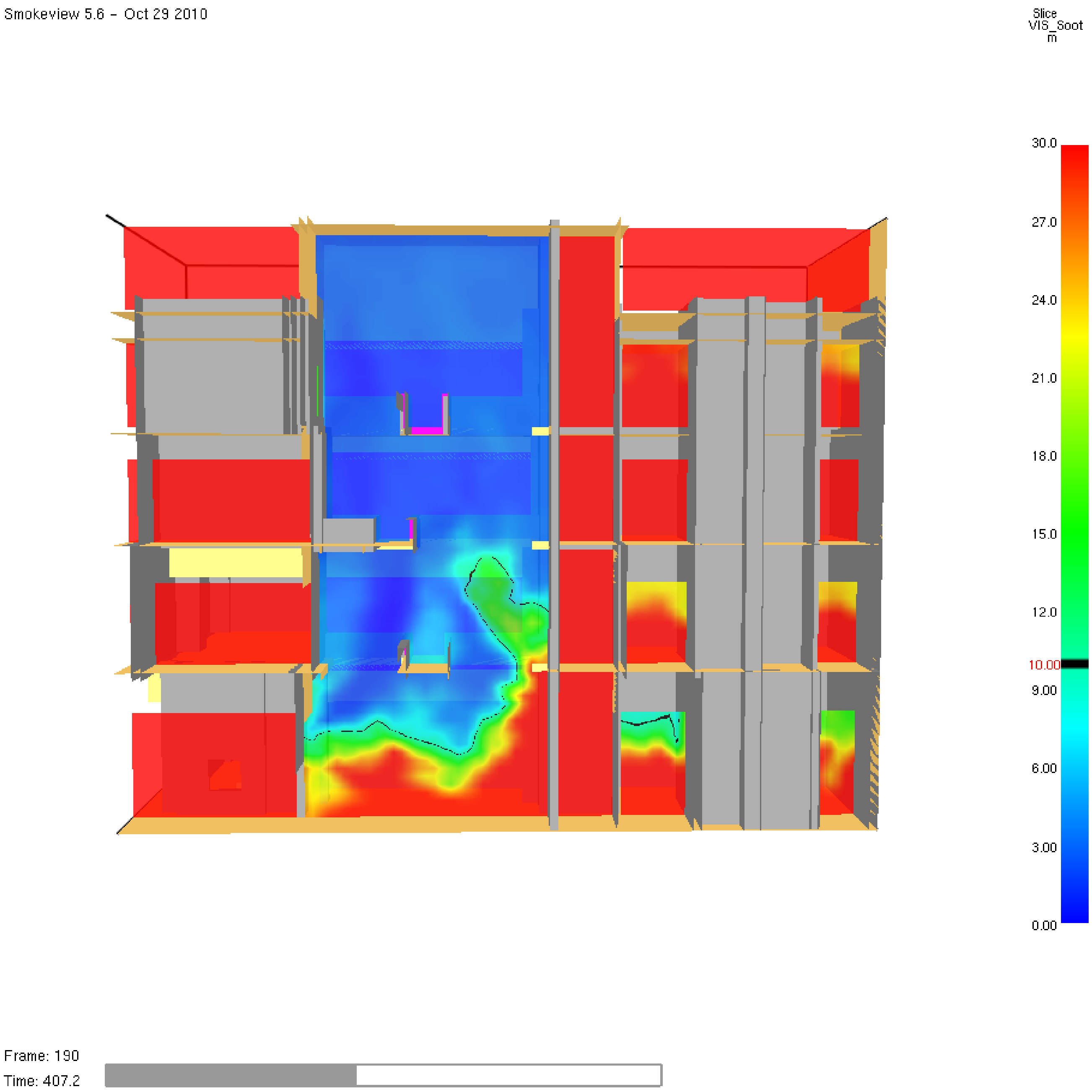

Figure 61 - Visibility simulation with curtains at 400+ seconds

As it can be seen on the right part of the simulations, there is a colour key, blue being complete lack of visibility, and red being full clear visibility.

It can be observed how this simulation is very logical: the higher volume of smoke in an area, the less visibility.

To see things more clearly, a vertical view of the first floor (the floor with curtains closer to the fire source) is required. This view is at 1.8 m from the ground of the first floor. This height was chosen according to the average height of a person, creating a simulation level with their sight.

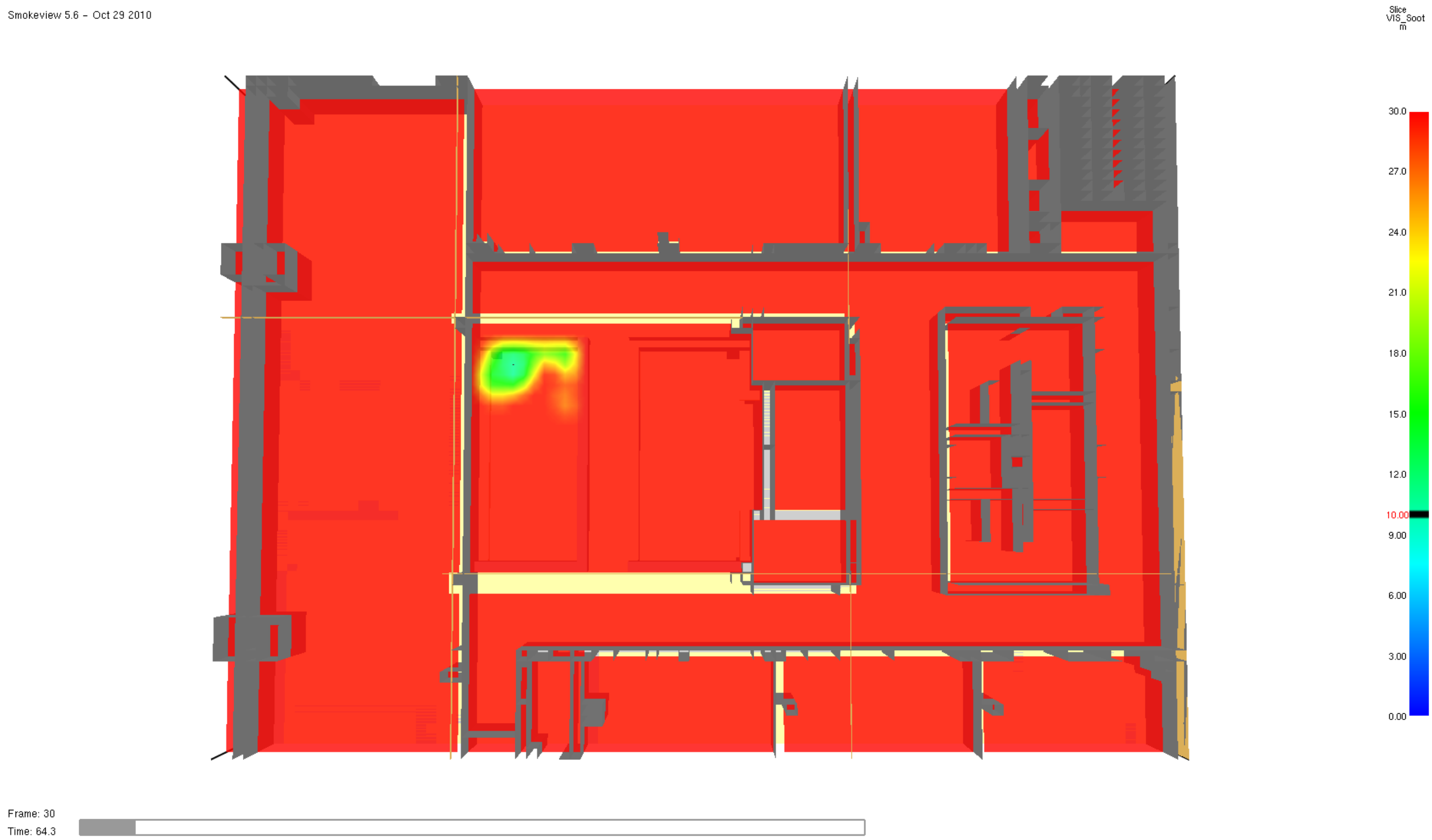

Figure 62 – Vertical visibility simulation with curtains at 60+ seconds

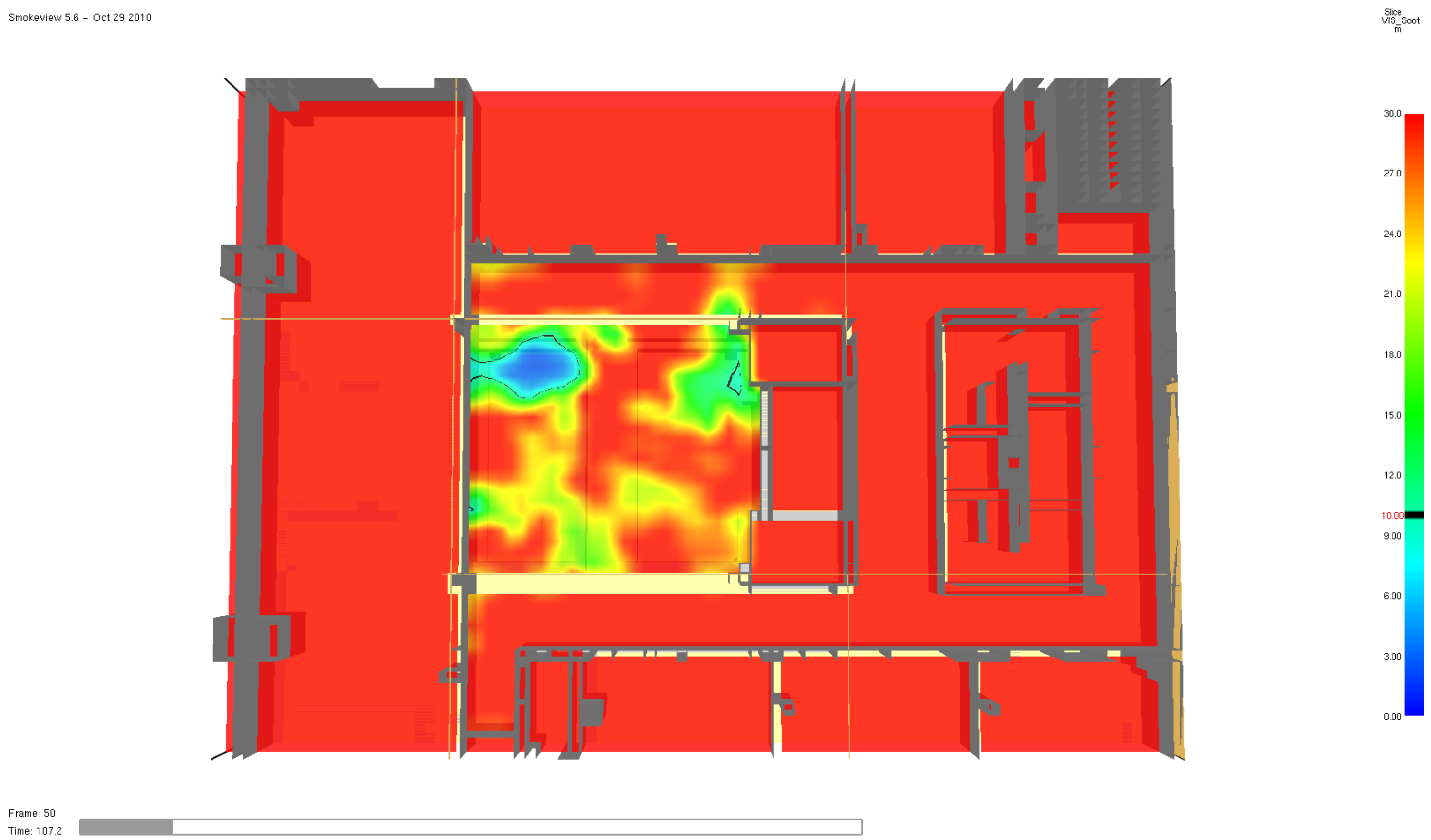

Figure 63 - Vertical visibility simulation with curtains at 100+ seconds

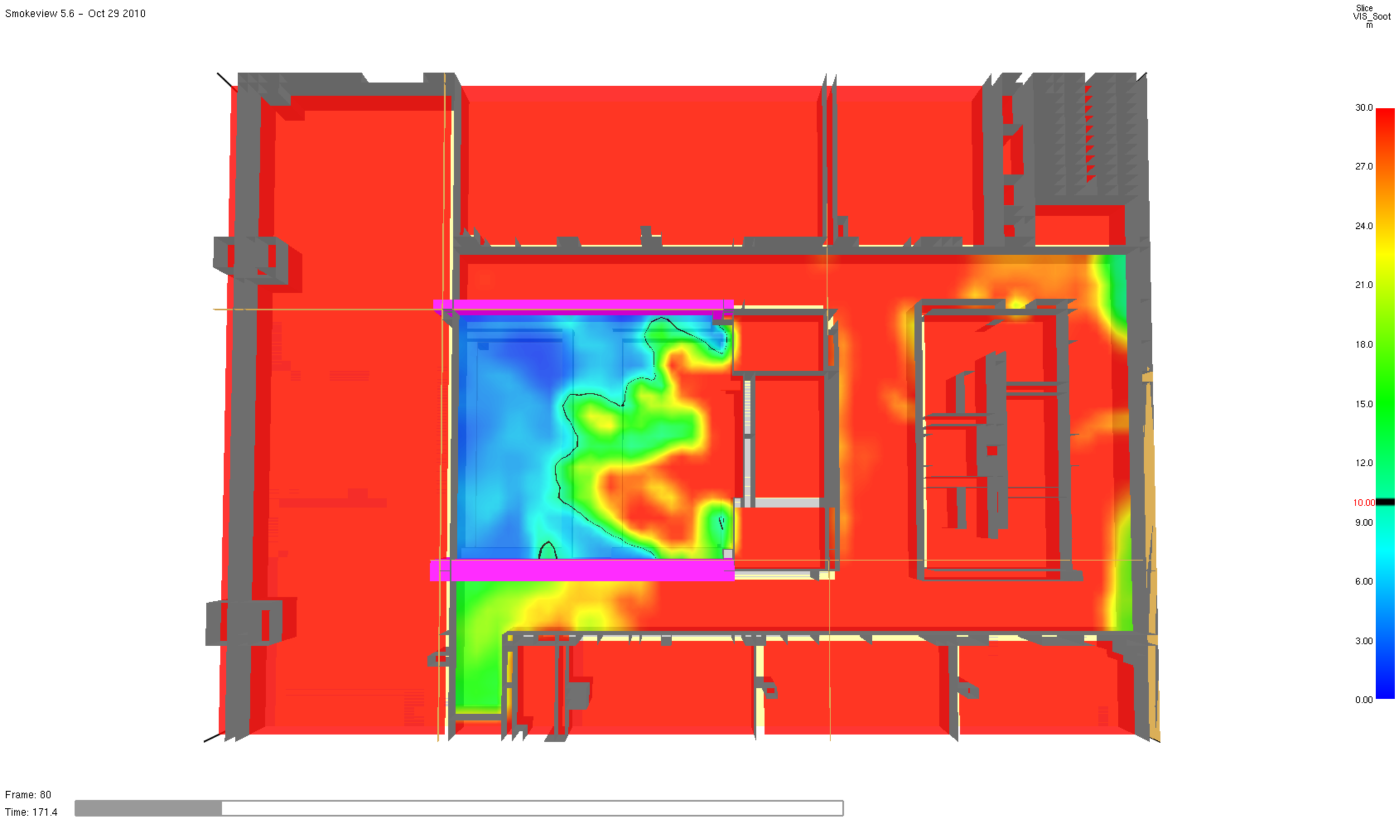

Figure 64 - Vertical visibility simulation with curtains at 170+ seconds

It can be observed how different parts of the corridors (on the right) have small quantities of smoke. This phenomenon can be explained by the deploy time of the curtains: they take a few seconds to reach the ground since the alarm is triggered. This allows smoke to enter the corridors during those seconds.

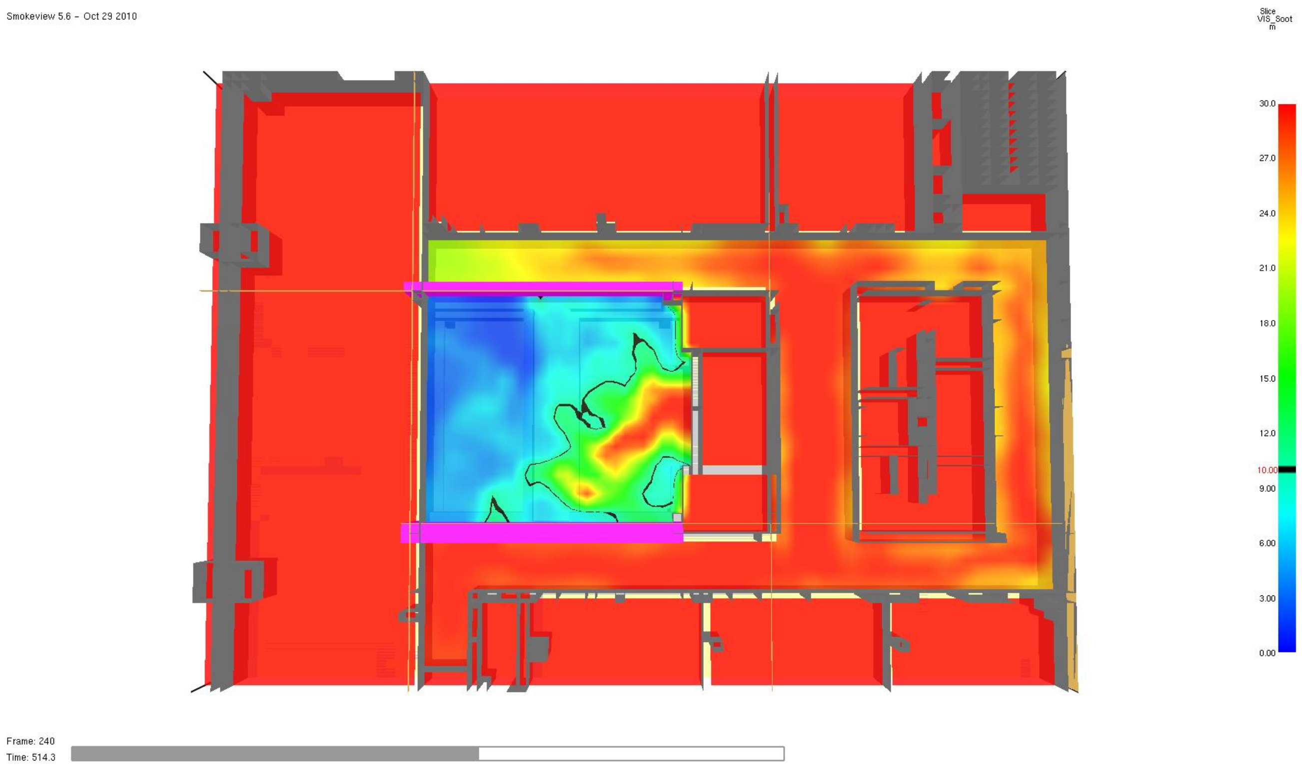

Figure 65 - Vertical visibility simulation with curtains at 510+ seconds

2) Without curtains

The same simulations have been created without curtains to compare the results with the previous paragraph.

First of all, smoke simulation:

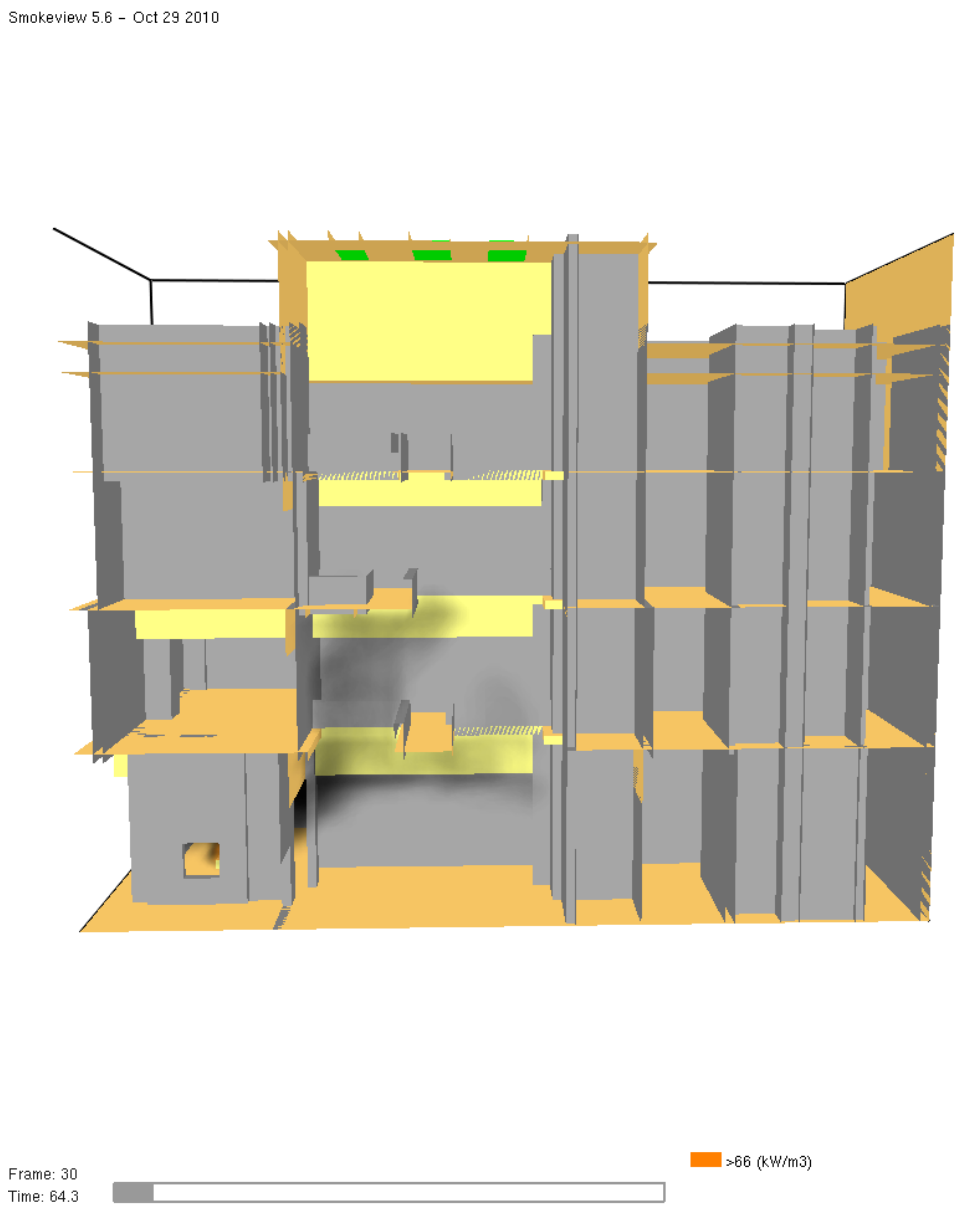

Figure 66 - 3D smoke simulation without curtains at 60+ seconds

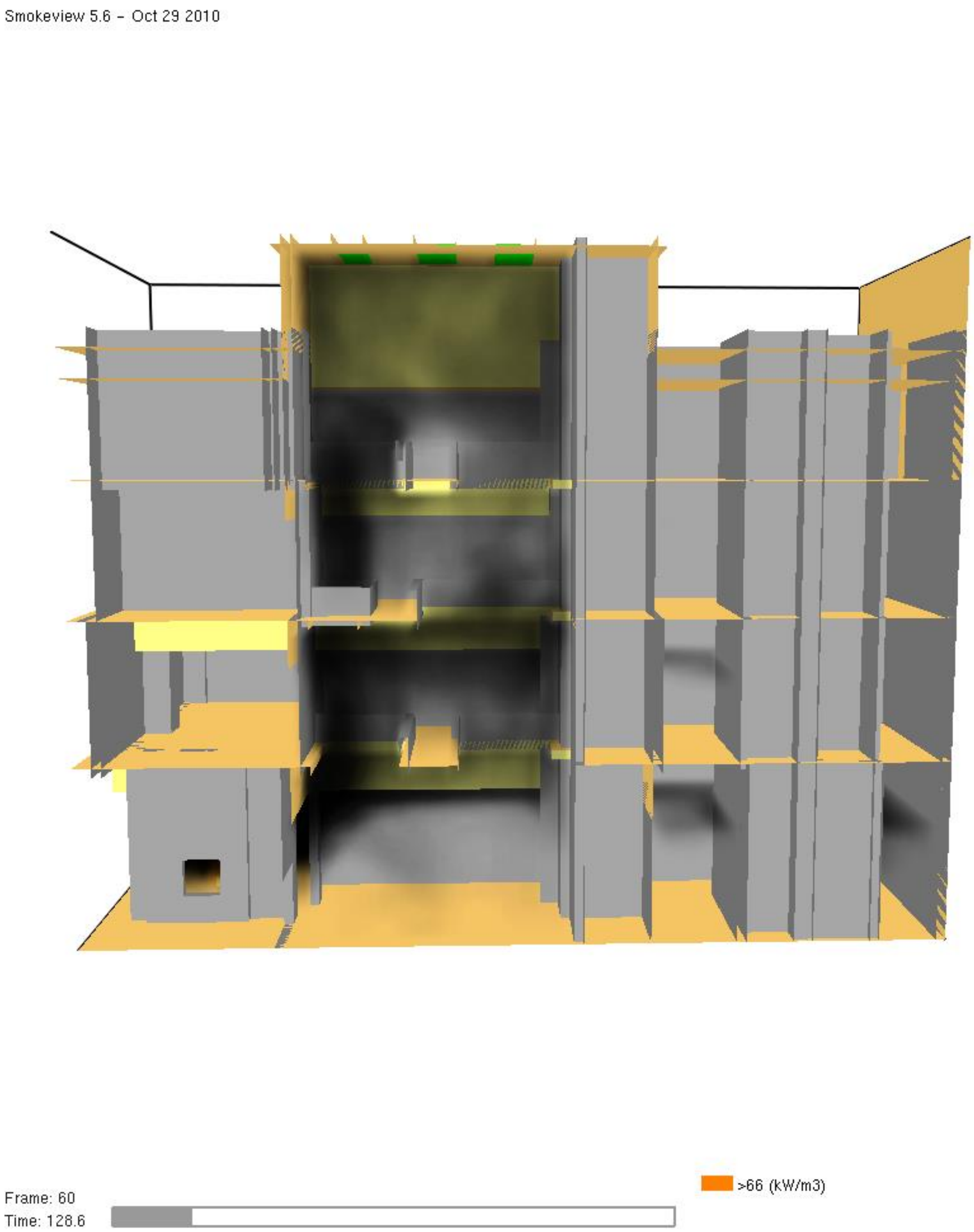

Figure 67 - 3D smoke simulation without curtains at 120+ seconds

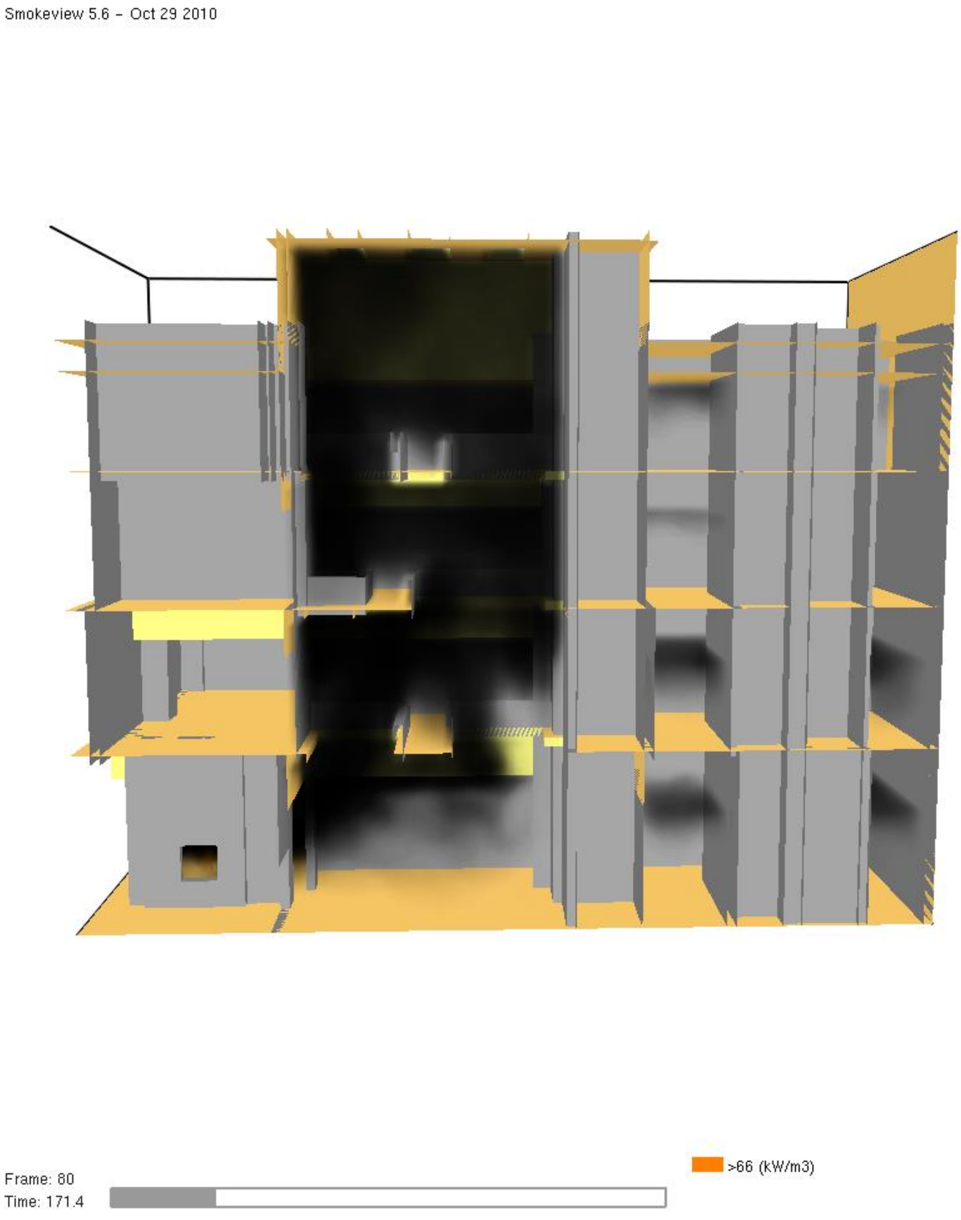

Figure 68 - 3D smoke simulations without curtains at 170+ seconds

The non-existence of curtains creates a huge difference in the corridors. As it can be observed, smoke fills practically all 3 storeys above the ground floor.

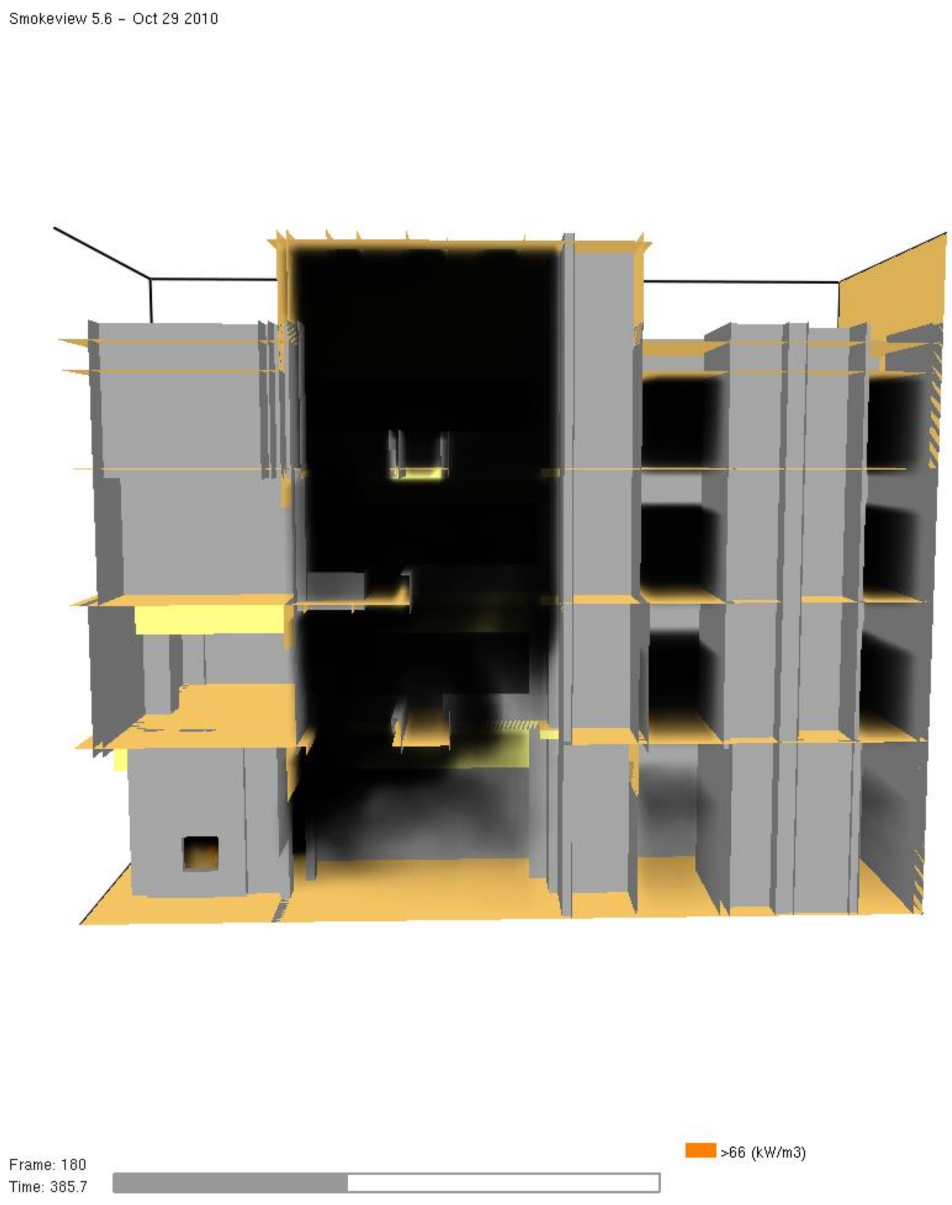

Figure 69 - 3D smoke simulation without curtains at 385+ seconds

For the visibility simulation, the next results were obtained:

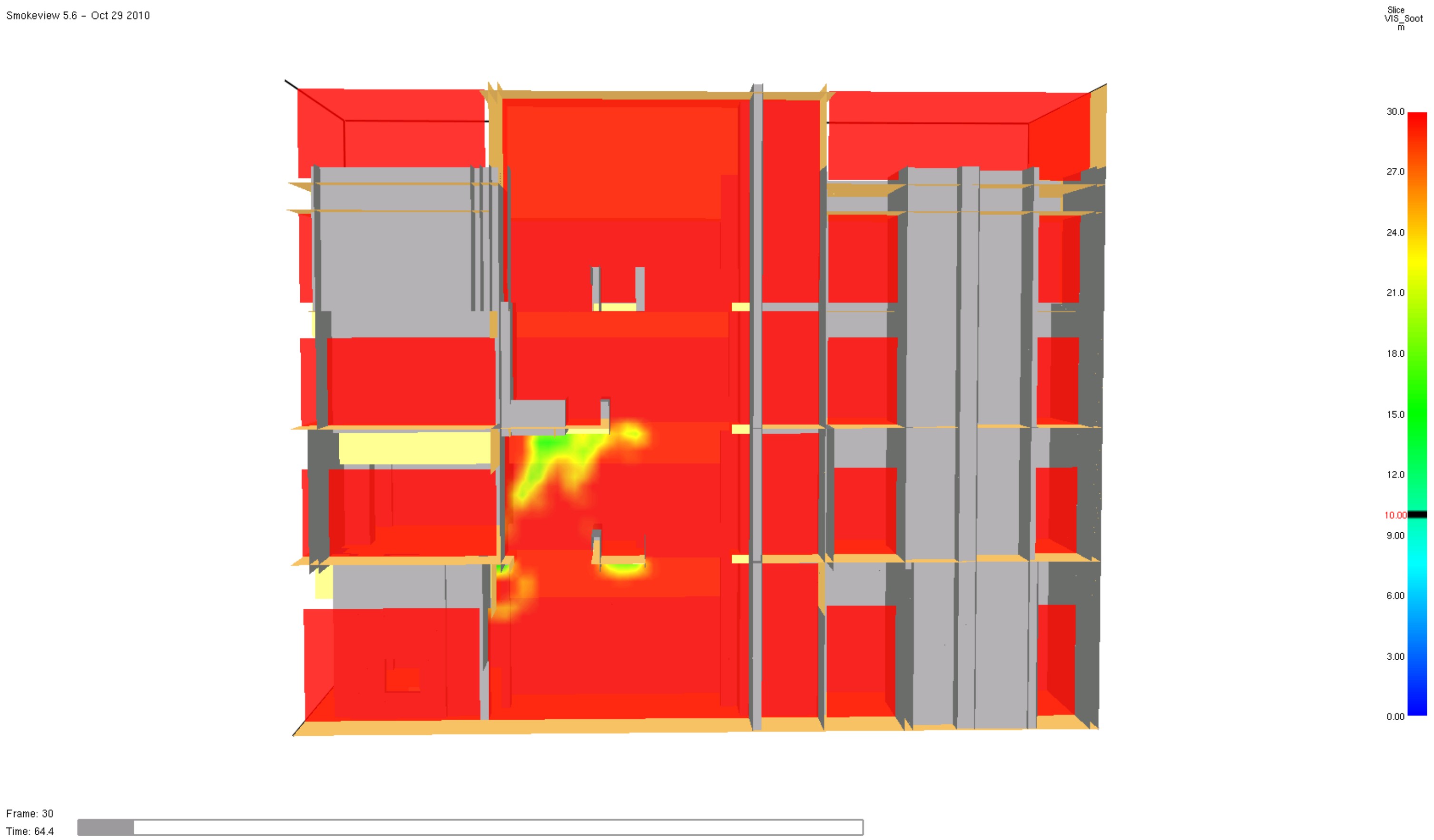

Figure 70 - Visibility simulation without curtains at 60+ seconds

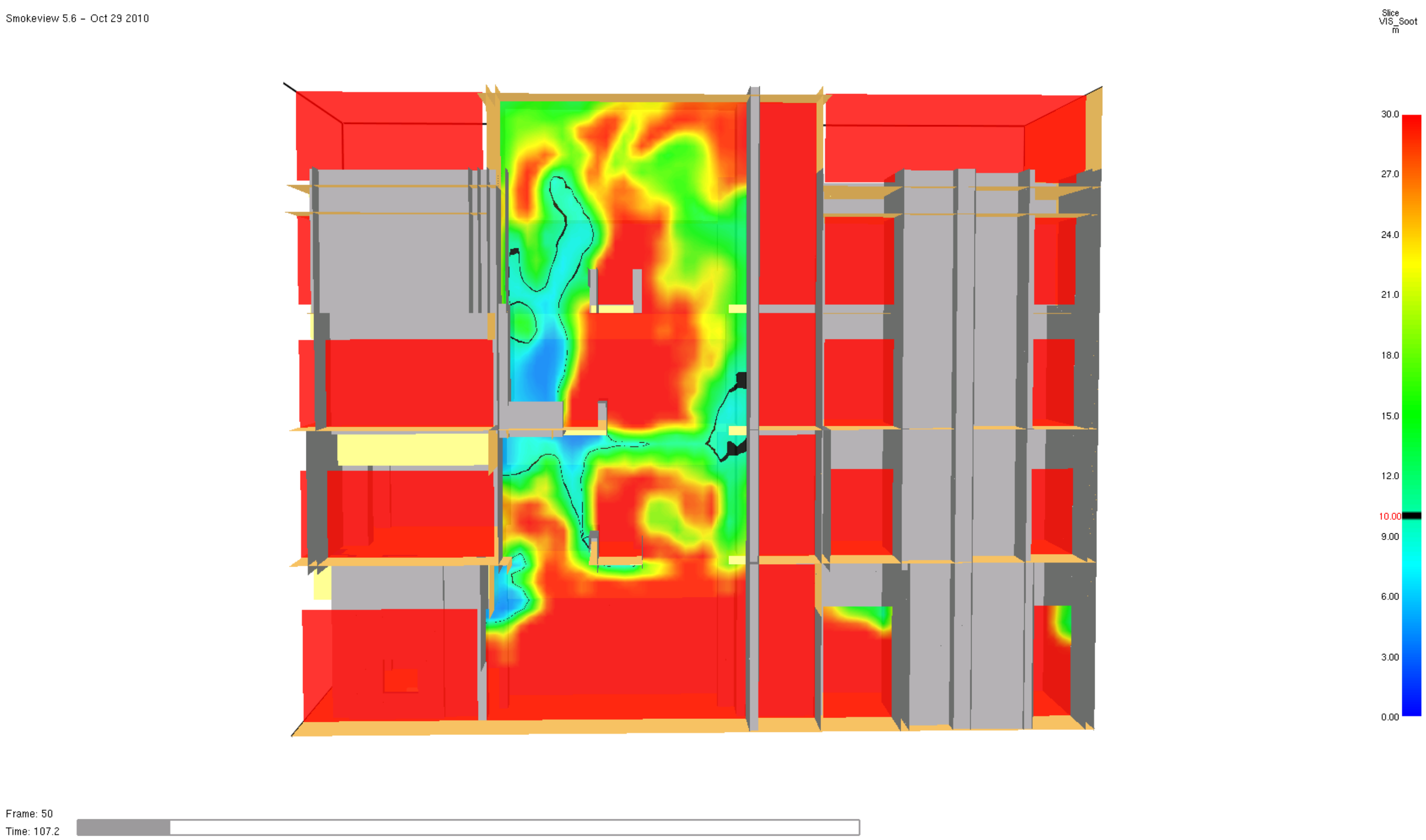

Figure 71 - Visibility simulation without curtains at 100+ seconds

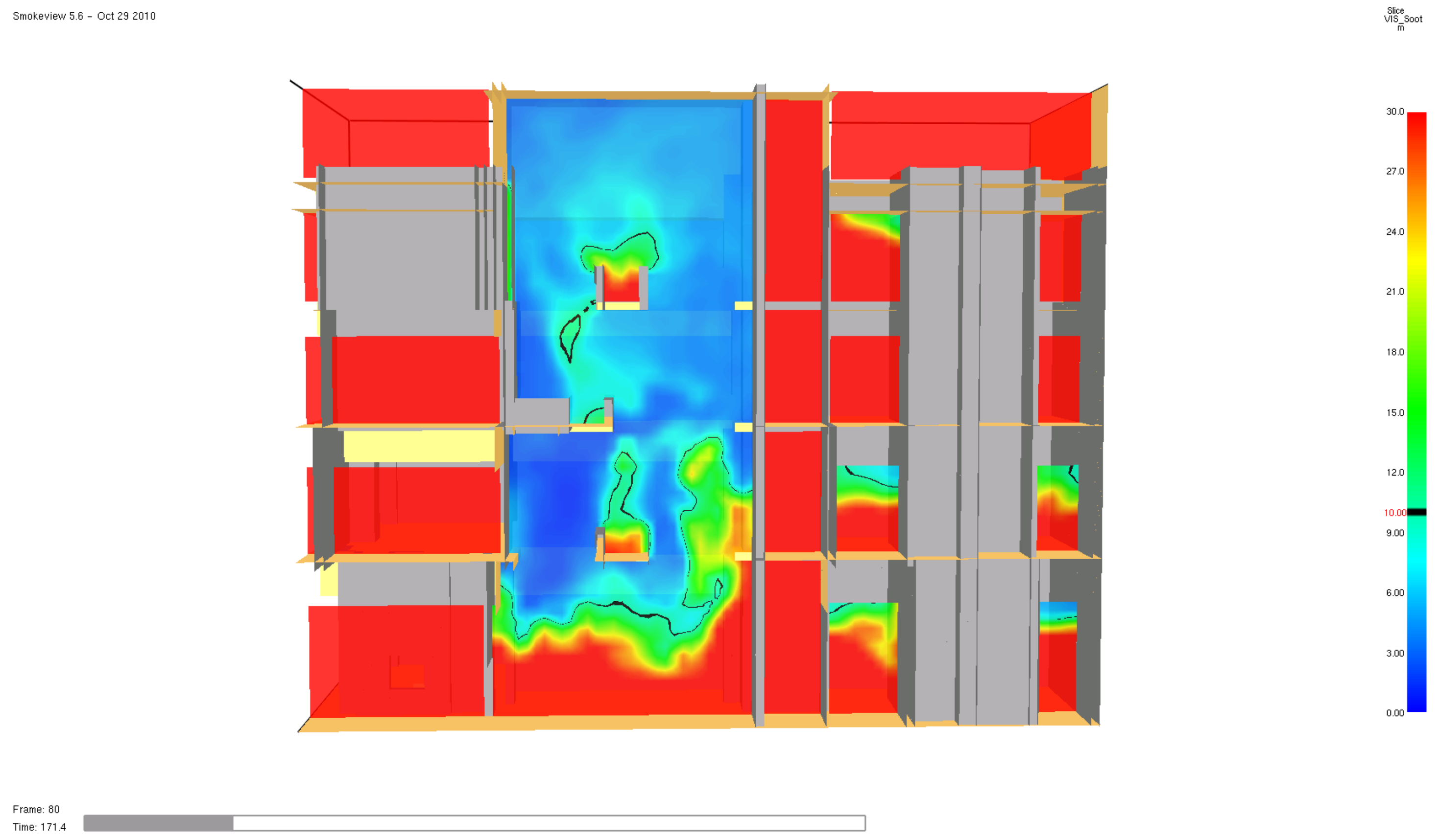

Figure 72 - Visibility simulation without curtains at 170+ seconds

Again, where there is smoke, visibility will be reduced. In this case, blue colour (very low visibility) is present in most areas above the ground floor. As a result, escape routes are much more difficult to reach for people trapped inside.

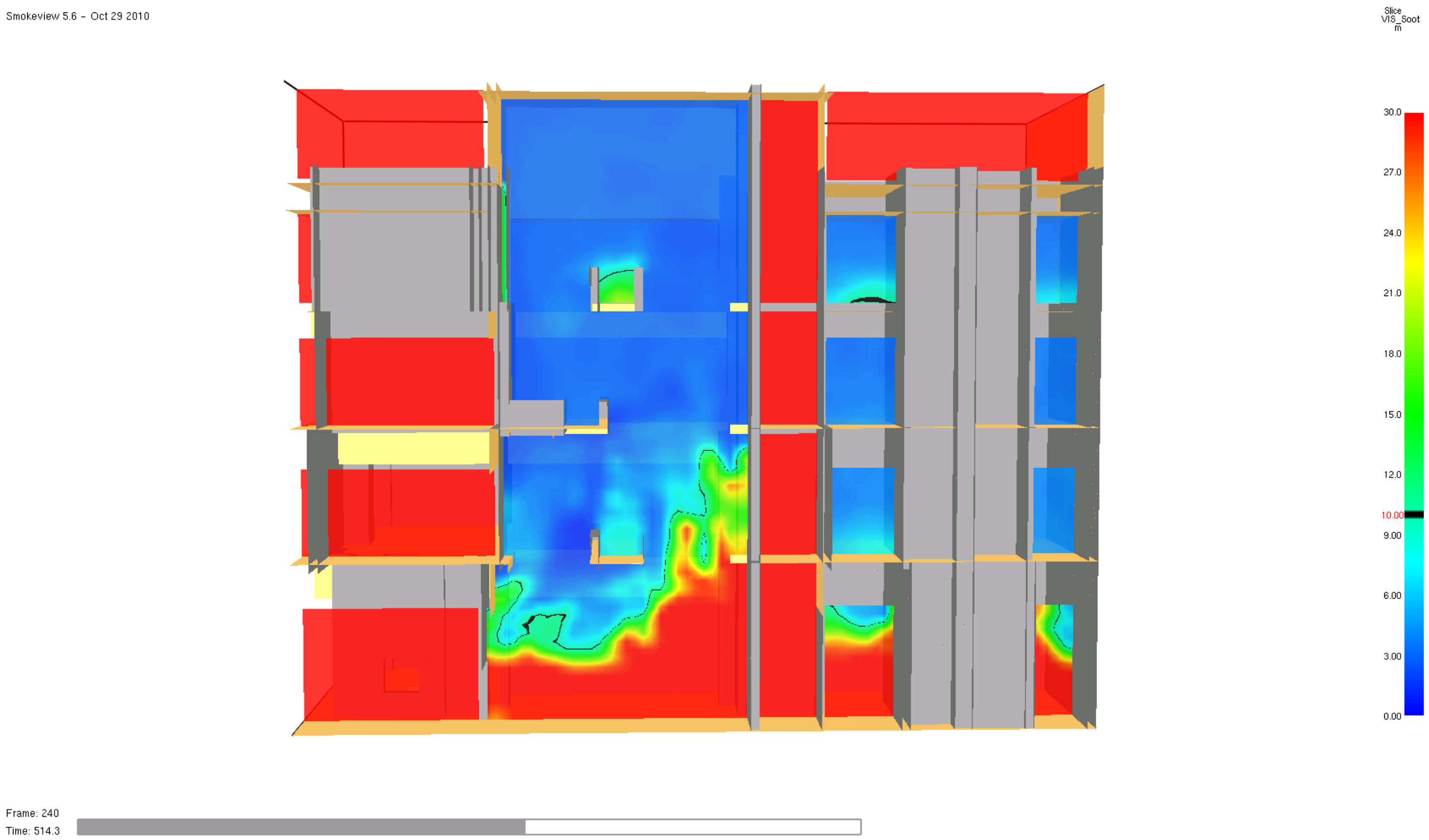

Figure 73 - Visibility simulation without curtains at 510+ seconds

Below is shown what happens on the first floor.

Figure 74 - Vertical visibility simulation without curtains at 60+ seconds

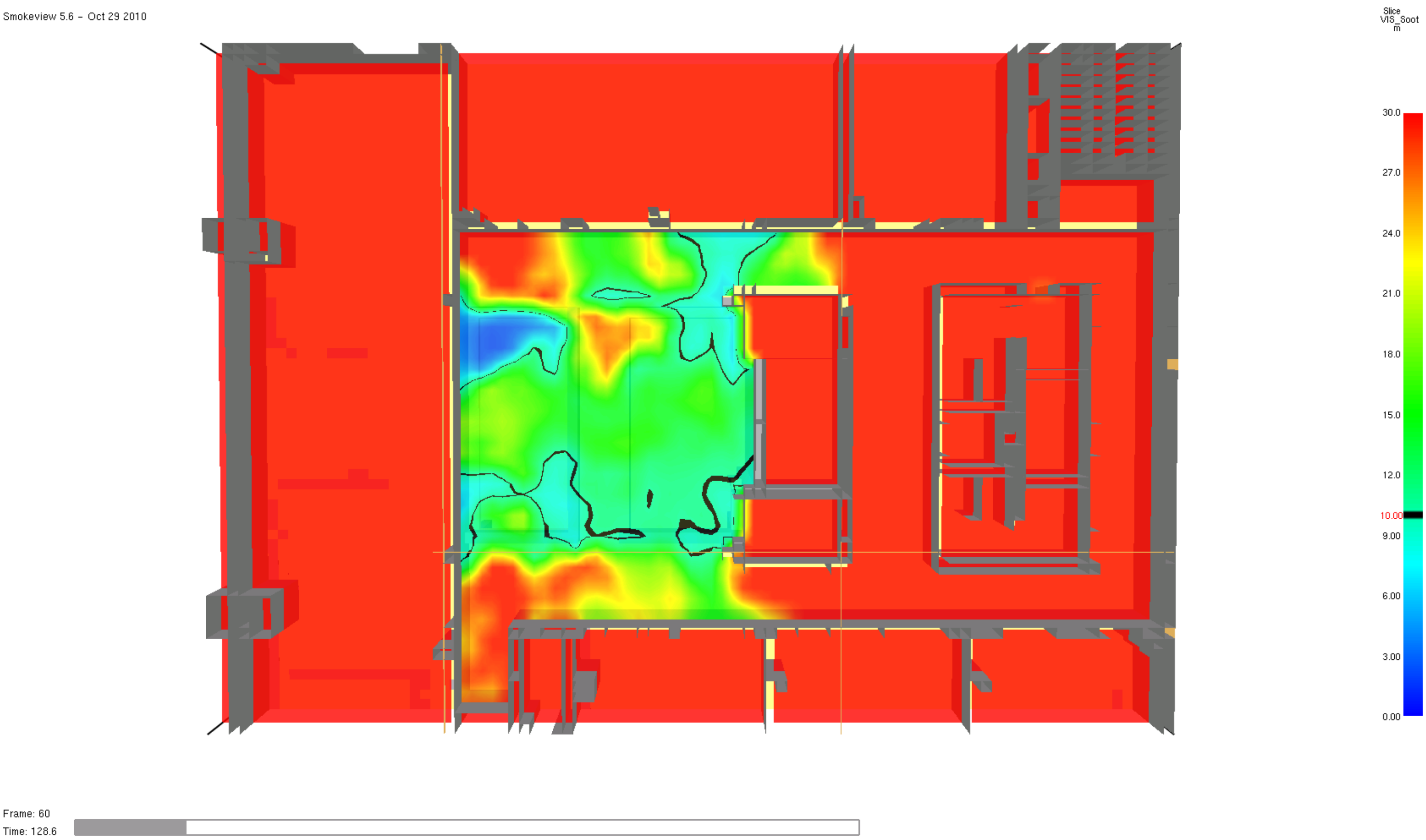

Figure 75 - Vertical visibility simulation without curtains at 128+ seconds

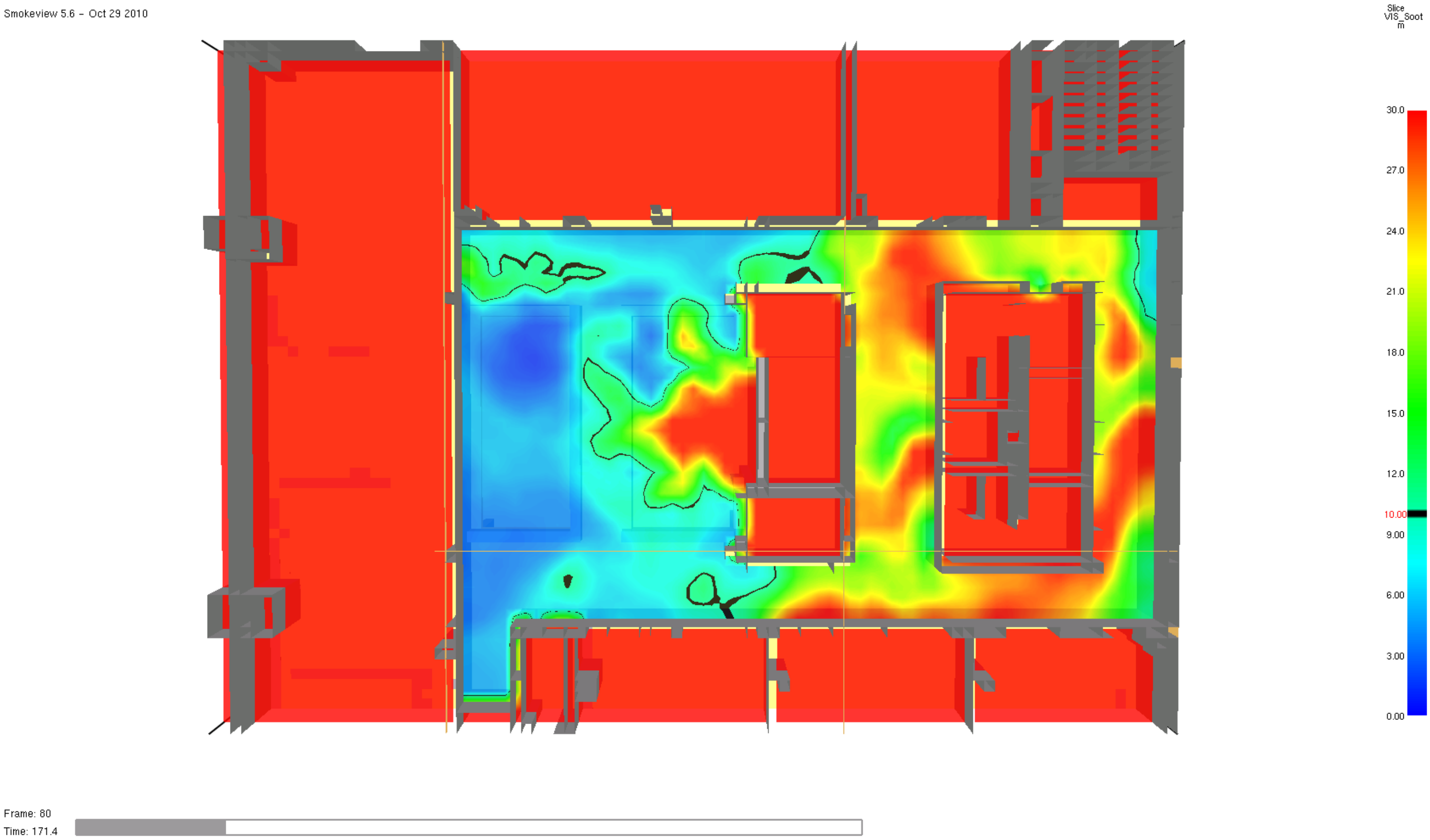

Figure 76 - Vertical visibility simulation without curtains at 170+ seconds

Blue colours are present in all the corridors. The non-existence of curtains, as seen below, result in a more chaotic scenario and the consequences can be devastating.

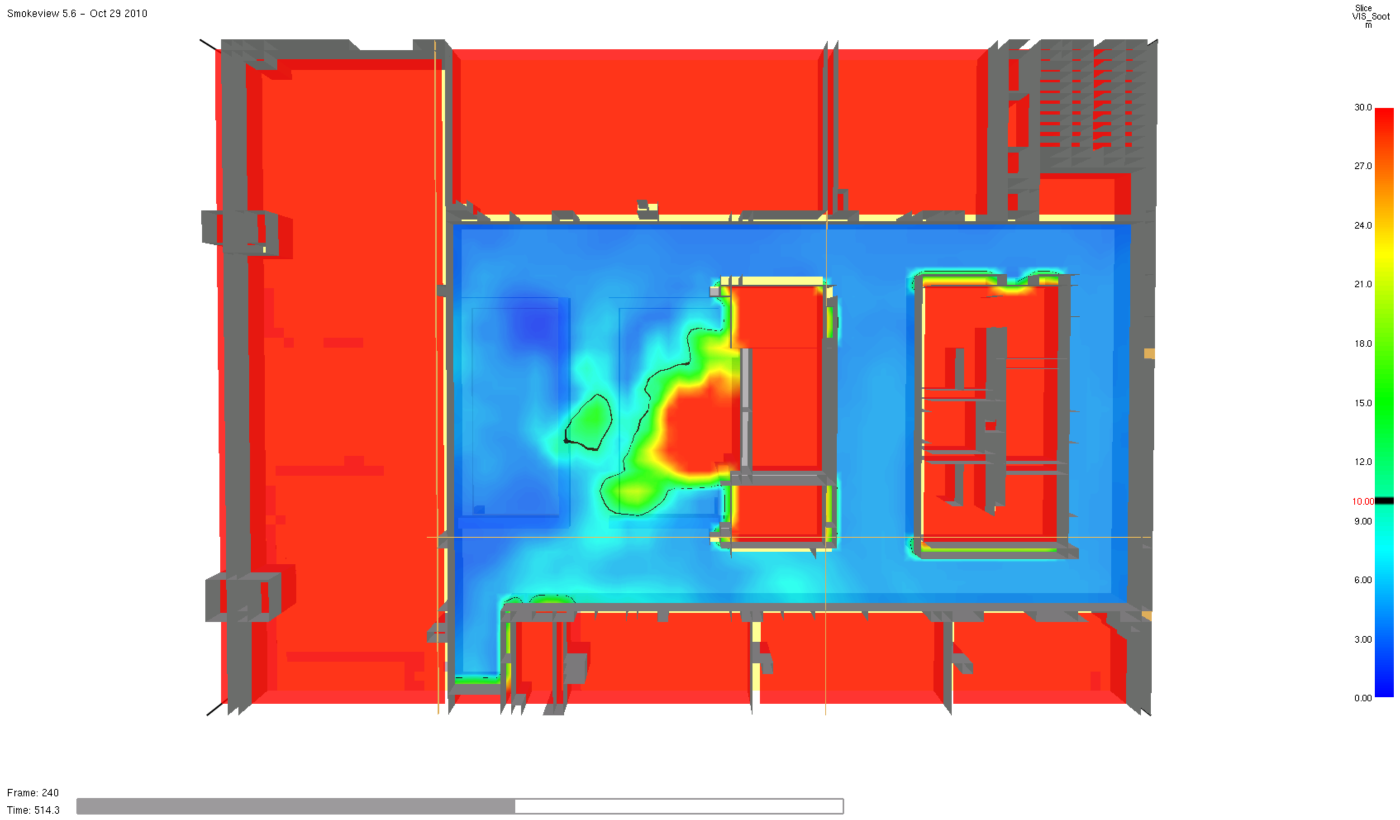

Figure 77 - Vertical visibility simulation without curtains at 514+ seconds

6. LABFACTOR SMOKE CONTROL SYSTEMS TESTS

The smoke tests were conducted in LabFactor in order to test the current fire safety elements of the building. There are various protective measures in LabFactor such as smoke curtains and smoke exhaust fans. It will now be illustrated how these safety elements behaved during the tests. It is shown below how the smoke exhaust fan grills of the atrium look when they are closed and inactive:

Figure 78 - Smoke exhaust fans grills closed

Behind the grills, there are exhaust fans which exhaust the smoke from the atrium into the air during a fire. Shown below is how they look like when opened:

Figure 79 - Smoke exhaust fans grills open

They open when activated manually and allow smoke to be exhausted. The mechanical smoke ventilation of LabFactor is very beneficial as it eradicates smoke efficiently and allows visibility to occur throughout the atrium within a short time.

The image below illustrates the smoke dampers opening when the fire alarm of LabFactor is activated:

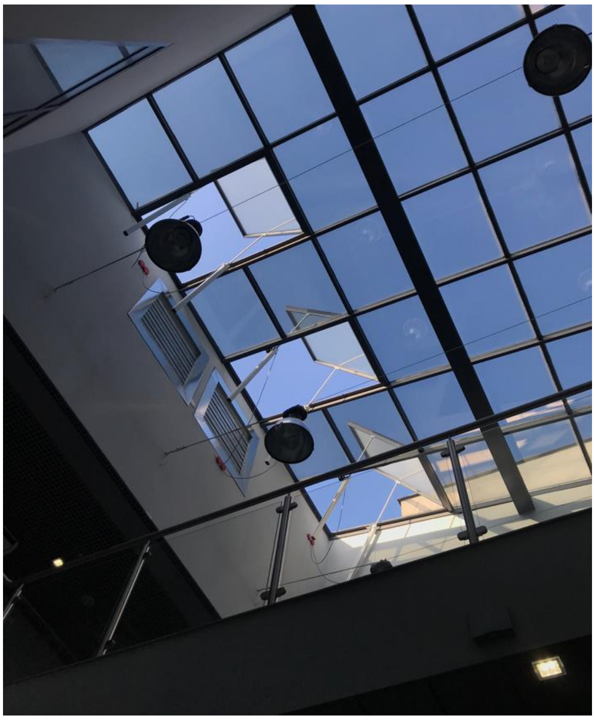

Figure 80 - Smoke dampers opened

The smoke dampers of the atrium ceiling act as natural smoke ventilation and allow smoke to travel out of the building. They are deployed automatically upon detection of smoke. However, this is not as effective as mechanical smoke ventilation as it does not extract the smoke out of the building as quick as mechanical smoke ventilation in case of buildings with high atriums.

The picture indicated below shows buttons used for raising the fire alarm and opening the smoke dampers:

Figure 81 - Fire alarm and smoke dampers switches

The red switch is the fire alarm and activates the alarm. Upon activating the alarm, loudspeakers which are situated at various points throughout LabFactor play voice messages about the detection of fire in different languages, both of the elevators descend to the ground floor and the smoke dampers as well as the doors on the ground floor open.

The orange switch initiates the smoke dampers and the doors on the ground floor which then allows the smoke to be removed from the building by natural airflow.

Now demonstrated below is how the grills and smoke machine were set up for the test. The grill was intended to create a fire with the smoke machine blowing thick smoke plumes directly above the flames to heat it up and let it flow to the roof of LabFactor to test the full power of the mechanical ventilation systems of LabFactor. This was positioned on the second floor of LabFactor on a bridge inside the atrium. Below are shown the grills set ablaze and the smoke machine producing the smoke:

Figure 82 - The grill set ablaze and the Machine producing the smoke

The smoke machine creates harmless smoke which after a few minutes is hard to breathe in because of its temperature and density. During that test the smoke curtains were deployed to show their effectiveness.

Portrayed below is the level of visibility during the smoke tests on the third floor of LabFactor:

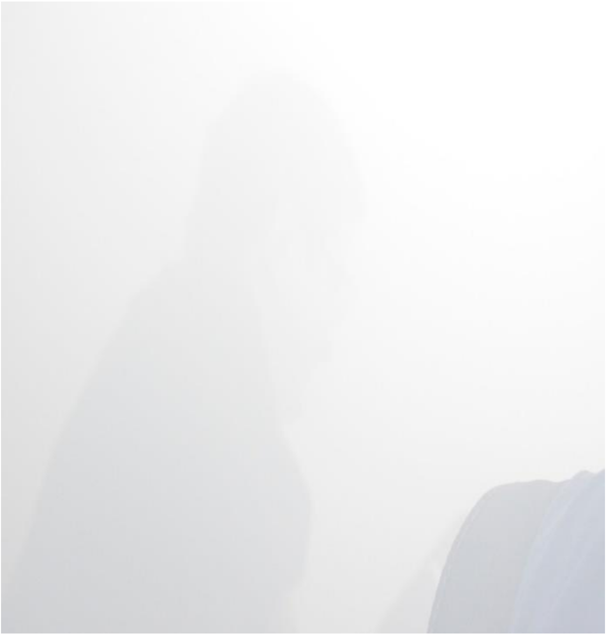

Figure 83 - The visibility on the third floor during the tests

When the atrium was full of smoke and the visibility was low enough, the mechanical fans were switched on to remove the generated smoke.

Figure 84 - The mechanical fans exhausting the smoke

Then the smoke was generated once again without fans working. When the smoke filled the entire atrium, the curtains were lifted and the occupants on every floor made their way to the nearest evacuation exit whilst following the signs. All the occupants were highly advised to utilise the two stairwells in order to exit the LabFactor building. Once they safely exited the building, everyone then rallied at the designated assembly point.

7. CONCLUSIONS

The objectives of this project was evaluating LabFactor fire strategy using theory, simulations and practical tests. Based on the results shown earlier in this document, it can be concluded that:

1. All fire protection systems installed in LabFactor are in compliance with Polish standards and regulations so the building and the people inside are well protected from the dangers of fire. The current LabFactor fire strategy not only meets the requirements of the baseline one, but also exceeds them.

2. Smoke curtains are extremely important for smoke control in atriums and large open spaces. Although they are not required according to Polish regulations - many buildings do not feature them - they help substantially in containing the smoke in one place and protecting the evacuation routes. Smoke curtains in LabFactor are not part of its fire protection system, but the smoke tests and simulations have shown how a fire situation can be changed with their presence. That is why **it is strongly recommended incorporating the smoke curtains into the actual fire protection system in LabFactor.**

3. Mechanical fans do help in removing smoke generated during fires. Even though the conducted Fire Dynamics Simulations have not shown major differences, the practical tests have. During them, the smoke was removed fast and the visibility improved noticeably. While natural ventilation systems have limitations, the fans can work independently and are also especially helpful in buildings with high atriums. As in the case of the smoke curtains, the fans are not part of LabFactor fire protection system. For the aforementioned reasons, **it is recommended incorporating the mechanical fans into the actual fire protection system in LabFactor.**

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