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French case study: design an energy-efficient and fire safe building. Final report presented at the 10th International conference on performance-based codes and fire safety design methods, November 10-12, 2014, Gold Cost, QLD, Australia

Elizabeth Blanchard, Mehdi Koutaiba, Olivier Teissier, Jean-Marie Alessandrini, Philippe Fromy

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**10th International Conference on Performance-Based Codes and Fire Safety
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**French Case Study:
Design an energy-efficient and
fire safe building**

Final report

Elizabeth BLANCHARD, Mehdi KOUTAIBA, Olivier TEISSIER,
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September 2014

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September 2014

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CSTB R&D Program: Risk mitigation

Research project: Fire risk and sustainable development

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Team composition and acknowledgements

Our team is made up members of the staff from Scientific and Technical Centre for Building (CSTB). CSTB is the French governmental agency for buildings that works with building sector and the domestic authorities to move towards improved quality and safety in buildings and its environment. Activities at CSTB are related to research, consultancy, testing, training and certification.

Olivier TEISSIER, Mehdi KOUTAIBA, Elizabeth BLANCHARD and Philippe FROMY are in the safety, structure and fire department at CSTB. In the present case study, they identify possible fire safety strategies. They define, run and analyze the simulations of smoke movement and people evacuation. Jean-Marie ALESSANDRINI is in the energy and environment department at CSTB. In the present case study, he plays the role of an architect designing a building.

Olivier TEISSIER is a student at the University of Aix-Marseille. He is finishing his master research on Fire safety science and engineering. The program of his formation is about fundamental foundations, measurements technics and fire numerical simulations. He has basic skills in French building standards, fire-fighting systems and post-fire analysis. He has been involved in the present study during his internship at CSTB.

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Elizabeth BLANCHARD is a fire safety engineer. She holds her PhD in mechanics and energetics from the University of Nancy, as well as a M.Sc.Res. and a M.Sc.Eng. in Mathematical modeling from the University of Bordeaux. Her research interests are interaction phenomena between water spray and fire, building fire safety level assessment with stochastic modeling, computer modeling and experimentation. For private customers, she designs smoke exhaust systems in public buildings like auditoriums, schools and historical buildings. She joined CSTB in February 2008 and is involved in the development of fire engineering codes.

Philippe FROMY has been a fire safety engineer since 1983. During this time, he developed several codes: 1 and 2 zone models for smoke movement in enclosures (NAT, FISBA, CIFI), model for people evacuation in buildings (code SEVE-P), model of heat transfer in fire resistance furnace, stochastic hybrid model for fire safety level assessment. He played a strong role during the French National Project for Fire Safety Engineering (PN-ISI) by leading actions related to people evacuation and fire modeling. Since 2004, he has participated to the application of the French regulations in place which introduces the performance-based approach in fire safety.

Jean-Marie ALESSANDRINI is an engineer in thermal transfer and energetic system. He has been working in the building industry since 1997 and for air conditioning manufacturer before. He is especially involved in bioclimatic design and interactions between different disciplines. He played a role during the elaboration of the French building thermal standard.

The authors would like to thank the kind contribution of:

Jean-Michel ATTLAN (SFPE) helps the project with his benevolence and enriches it thanks to his international vision of fire safety. Jean-Michel ATTLAN is the founding and first president of the SFPE French Chapter. During his entire professional career as fire safety engineer for Factory Mutual, Renault, the World Bank and Accor, Jean-Michel ATTLAN has been a strong supporter of fire protection engineering as a powerful tool to overcome conflicting interpretations of local codes and standards in a globalized world. Jean-Michel ATTLAN is now retired but continues to promote a wider use of modern fire safety engineering techniques and methods in France and in Europe.

Lieutenant-Colonel Pascal GOUERY (SDIS91) is a fire-service superior officer. He is responsible of risk prevention in buildings in the French department Essonne with 1.2 millions of residents over 1800 m². Thanks to his knowledge of the French standards, Lieutenant-Colonel GOUERY identifies the noncompliance of the proposed building. He also answers to the following questions: How would we proceed to design such a building in France? What is not authorized by the French standards? What would require the authorities to authorize such project? Moreover, Lieutenant-Colonel GOUERY contributes deeply to the fire safety strategy design.

Abstract

The present study is conducted in the frame of the 10th International Conference on Performance-Based Codes and Fire Safety Design Methods. It deals with the case study proposing a building and setting a few specifications. Our approach is original since we adopt a performance based approach in both energy efficiency and fire safety. Indeed, both studies are conducted in parallel. There are three main results. Firstly, the present study demonstrates the feasibility to adopt such a combined approach. Secondly, it shows the possibility to use the same technical equipment (double skin façade) to ensure dual roles, both for energy efficiency and in fire safety. Thirdly, the study proposes an alternative to solutions relying only on technical measures to ensure energy efficiency, thermal comfort and fire safety. The final solution is based on a combination of technical and organizational measures.

Keywords: Energy efficiency, fire safety, performance-based approach, open spaces

Résumé

La présente étude est conduite dans le cadre de la 10^{ème} édition de la conférence internationale « Performance-Based Codes and Fire Safety Design Methods ». Elle traite du cas d'étude proposé par la conférence qui spécifie un bâtiment et un certain nombre de prérogatives à respecter. Notre approche est originale, nous avons adopté une approche performantielle aussi bien en performance énergétique qu'en sécurité incendie et les deux études ont été menées en parallèle. L'étude conduit à trois principaux résultats. Premièrement, cette étude démontre la possibilité d'analyser en même temps la performance énergétique d'un établissement, et sa performance au regard du risque incendie. Deuxièmement, cette étude montre la possibilité d'utiliser un équipement (la façade double-peau dans le cas présent) permettant d'assurer à la fois la performance énergétique et la sécurité incendie de l'établissement. Enfin, troisièmement, l'analyse conduit à proposer une solution qui se veut être une alternative à des solutions reposant uniquement sur des mesures techniques, ce à la fois pour assurer la performance énergétique, le confort thermique et la sécurité incendie de l'établissement. La solution proposée à l'issue des travaux repose sur des mesures techniques et organisationnelles.

Mots clés : Performance énergétique, sécurité incendie, approche performantielle, open spaces

Summary

The present study deals with the exercise proposed by the 10th International Conference on Performance-Based Codes and Fire Safety Design Methods. In that frame, a partially described building and a few specifications are given. This conference represents a great opportunity to compare and enhance professional practices of fire safety actors in the world. In this edition, the building presents the particularity to get its levels largely interconnected. All five office levels are interconnected by an open stairway on the south side and by floor voids. Such a configuration constitutes a great challenge to fire safety.

In addition to case study specifications, the current trends in France motivate us to deal energy, thermal comfort and fire safety, all in parallel for the studied building. The approach consists in performance-based assessment of designed building in both energy efficiency and fire safety, this building being first knocked based on French building standards.

The present study demonstrates the feasibility to adopt such a combined approach in these different domains. The major interest is to recommend measures in resonance and not contradictory.

Moreover, the present study demonstrates the possibility to use the same equipment (double skin façade) to ensure two roles, both for energy efficiency and in fire safety. In comparison with more current buildings where design regulations are independent and thus applied independently, the added value of such a solution is real, for technical, economic and environmental reasons.

Last, the present study proposes an alternative to solutions relying only on technical measures to ensure energy efficiency, thermal comfort and fire safety. The final solution is based on a combination of technical and organizational measures.

The final solution should be completed by a societal analysis about working conditions and working adaptation to manage degraded conditions for specific open spaces.

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INTRODUCTION

To Build or not To Build, a 50 000 m³ open space?

The goal of the exercise proposed by the conference SFPE is to build a fire protection security policy with the aim of protecting people and goods. A partially described building is also given. Thus, it represents a great opportunity to compare and enhance professional practices of fire safety actors in the world. When our team discovered the proposed building, the large number of interconnections between levels struck us. Indeed, it leads, on aerologic point of view, to get only one indoor space and of course, it strongly increases difficulty and thus interest for fire safety. At that time, we wondered why the building owner and his architect decided to have a nearly 50 000 m³ undivided space? What was their mind, their bias for conception when they imagined this building? What are the advantages for consumers to work in such a building? And consequently, we wondered if we had to build or not a nearly 50 000 m³ open space? Our work began with this last question.

Consequently, other questions rose: How people can live and work in such a huge space? Can it be comfortable, it means not too cloudy, not too windy, not too cold, not too hot whatever the weather of the day? The lack of specifications for the proposed building has been used to imagine a context, a story to this building and to bring it to life. The current energy requirements have been our thread to describe the building, its internal layout, its occupancy, and its occupants' behaviors. Thus it gives a technical and behavioral situation to build a fire safety policy in order to answer YES to our opening question.

CONTEXT

Since the Kyoto Protocol was adopted in 1998 [1], the European Union has strived to limit global warming and to reduce its dependence on international energy sources like fossil fuels (gas, oil). In France, according to the French Environment and Energy Management Agency [2], the energy bill amounted in 2011 to 61.4 billion euros, representing 3.1% of its GDP and 88% of its trade deficit. Among all economic sectors and since 1973, the building sector has been the larger energy consumer. In 2011, this sector represented 44% of total energy consumed. In order to reduce energy needs of the buildings sector and greenhouse gas emissions, the French thermal regulation for buildings has been strengthened. These reinforced requirements address the energy-efficiency and the carbon footprint reduction of buildings by controlling energy use (heating, air conditioning, energy, hot water, sanitary water, lighting, etc.). In addition, the emerging environmental issues in the buildings has made rise new concepts such as BBC¹, the positive energy buildings², the German

¹ BBC for "bâtiment basse consommation" in French, a low energy building in English. This term is introduced in a French legal document: Arrêté du 8 mai 2007 relatif au contenu et aux conditions d'attribution du label « haute performance énergétique », Ministère de l'Emploi, de la Cohésion sociale et du Logement, 15 mai 2007, NOR : SOCU0750649A

² It does not exist an official definition of this term. However, the common idea is that the building is consuming less energy than its renewable energy production

PassivHaus³ [30] or the nearly zero energy building at the European scale⁴. Even different, all agree on drastic reduction of energy consumption.

To this day, the environmental concerns have led designers to conceive buildings where their architecture and their operating conditions answer to energy-efficiency requirements. In practice, they aim at taking advantage of the local climate by promoting air circulation, heat from sunshine and the diversity of activities to pool energy and reduce energy needs. Their solutions also require a strong link between all spaces in the building and its activities.

In parallel, fire safety implies to respect a number of common standards imposed by regulation. The French fire safety management is specific. It aims at maintaining a free-smoke area near the floor as long as possible. This strategy has two main objectives. At first, it promotes the self-evacuation of people. Then, it aims at improving the operating conditions of fire-fighters. This fire safety management is ensured by a large sample of systems, including mainly ventilation systems and passive protection. These requirements restrain building conception by making compulsory a number of stairways, their width, used materials, compartmentalized spaces for instance.

In that context, conceive buildings which respect French fire safety standards and where architecture and operating conditions answer to energy-efficiency requirements is a fundamental change in design practice. It can be endured with difficulty especially when constraints are not in resonance and seem contradictory like in the example mentioned above with open space and compartmentalized space. Indeed, from designer point of view, such requirements can appear as an impediment to innovation. It can be compared to a layer cake with layers of constraints which corresponds each to its own domain (energy, acoustic, fire safety, seismic, etc.). Moreover, all these constraints induce an increase in the costs for construction. For instance, evolution in French building standard over 1990 to 2005 has been evaluated to be responsible of an increase of residential building construction cost between 3.49 and 4.55 % according the building localization in France and its nature when total residential building construction cost increases of 30 % [14]. In the last ten years, total residential building construction cost still increases of 30 %⁵ while requirements for residential building have evolved strongly in at least energy-efficiency and seismic.

³ “Passive houses are buildings which assure a comfortable indoor climate in summer and in winter without needing a conventional heating system”. It is a standard which has been developed by the European project Cepheus (<http://www.cepheus.de/eng/index.html>)

⁴ About NZEB, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) propose following definition: “nearly zero-energy building means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.”

⁵ This information available on the website of the National Institute of Statistics and Economic Studies (http://www.insee.fr/en/themes/conjoncture/indice_icc.asp)

OBJECTIVES

As part of the case study of the 10th International Conference on Performance-Based Codes and Fire Safety Design Methods, we propose to deal energy, thermal comfort and fire safety, all in parallel for the studied building. The first idea is to assess if it is feasible to design a building for energy efficiency first and then to make it sufficiently safe for people and firefighters in case of fire and sufficiently resistant to limit damages to repair after fire. The second idea is to assess if constraints on design related to energy-efficiency requirements are in addition to the ones on fire safety or if designers can cope all constraints with the same construction processes or systems.

APPROACH

In order to confront energy and fire safety concern, our approach includes three stages. The first stage aims at imaging how the building works under normal operation conditions in such a way as to exploit the potential for energy sobriety. The building is designed so that to ensure occupant's comfort and hygiene within the building. Then, the second stage aims at defining the fire safety strategy which allows to meet the life and safety goals following both the case study building specifications and the French building standards. Also, our personal objective is to propose an alternative to a 100% sprinkler protection of the building by focusing instead on

1. Structural characteristics of a modern, energy efficient and green building
2. Evacuation routes and smoke management with provisions for people with disabilities.
3. Fire safety organization and human response by occupants and fire brigades.
4. Evaluation of this strategy and comparison with other alternative strategies.

The last stage questions the two approaches to identify if they are in resonance and contradictory.

1. BUILDING DESIGN

The SFPE exercise gives few information about the building, but does not deal with local climate and occupation. Main items are reminded in order to introduce principles, that we imagined, which led the conception. It gives the guideline to complete a project program. Thus a context is proposed with an outside environment, an internal layouts and building occupancy. Finally, operating conditions and technical solution are specified.

1.1 CASE STUDY BUILDING SPECIFICATIONS

The building is a corporate headquarters office located on the bank of a river. It contains a total of 8 floor levels (L1 to L8). The building foot print is 100 m x 30 m. These dimensions are supposed to be taken between interior faces of the walls. The facades on east, south and west side of the office levels are glazed curtain walls to maintain a clear view of the river on the south side and to promote natural lighting.

The building is a mixed-use, consisting of retail stores and carparks on the lower floors and office space on the upper floors. Figure 1 gives a schematic representation of the building by specifying for each level its activity. The first three floor levels (L1 to L3, in grey on Figure 1) are carparks with the vehicle entry via a lane way located on the north side. Some retails areas are located on the perimeter of the building on level L1. They have direct access/egress to the outside. The last four floor levels (L4 to L8, in blue on Figure 1) are offices. The main entry to the office levels is located on L4 on the west side, facing the main street. Access to the main entry is via a stairway leading from the street level to L4. Carpark level L1 is partly below ground, L2 is on the garden level.

All five office levels (L4-L8) are interconnected by an open stairway on the south side, an elevator located at north serves each level. The five office levels are interconnected by floor voids.

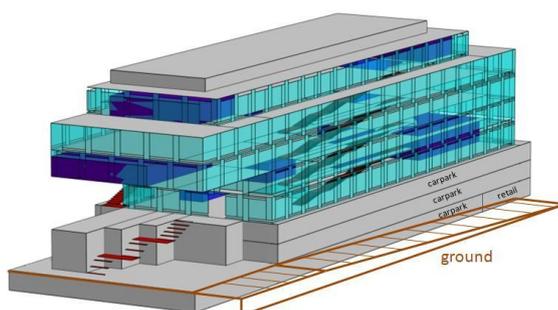


Figure 1: Schematic representation of the building

1.2 APPROACH AND BIAS FOR CONCEPTION

The present report focuses on qualitative aspect of building occupancy, comfort, hygiene and energy efficiency. Building is designed in three main stages summarized on Figure 2.

A building is designed for ensuring its main purpose: preserve occupants and their activities under the best comfortable, wholesomeness and safety conditions. We supposed that the draft project

follows this basic principle. Furthermore, we have added a complementary principle owing to the current energetic context. We suppose that the building should be designed to manage heat reconversion or evacuation of energy flux across the envelope to ensure thermal comfort. These fluxes result from activities, heat from sunshine and air exchange with outside.

Firstly a climate is chosen. A Provençal climate is selected. More precisely, we suppose the building is located in the south of France in Avignon in France. This city where successive popes resided intersects with the waterway Le Rhône. Due to its orientation, the building could be situated in the street “Chemin de la Traille”. We begin by imagining how the building works under normal operation conditions. Also, we define building internal layout in accordance with its activity and the draft building. The building proposed in the case study being hardly compartmentalized, we conserve this mind by promoting undivided space on office levels. Then, building occupancy is deduced. Activity and occupancy leads to internal heat gains (lighting, electronic devices, human activity).

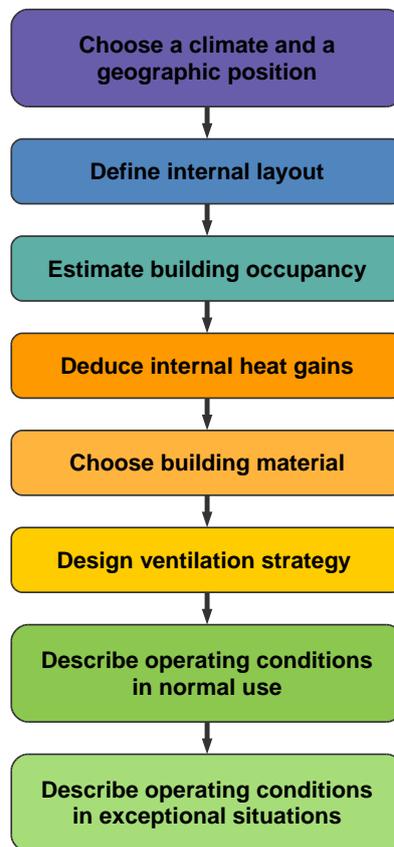


Figure 2: Our approach in building design

Secondly, a technical solution, adapted to the context, namely activities and climate, is proposed to ensure comfort and hygiene. The building proposed in the case study is characterized by glazed curtain walls with many floor voids between office levels. Thus, it promotes air flow at the overall office levels. Also, we propose to ensure comfort and hygiene by making marginal use of air conditioning systems, the final goal would be to ensure indoor conditions compatible with office

work only with the help of passive operation of such systems. Therefore, choices are made with regard to the choice of materials and the ventilation strategy. They aim at promoting a maximum use of natural air flow yielded by the thermal gradient between internal and external air and also between highest and lowest office levels. The choices are reinforced by the internal layout with maximum open workspaces. Normal operating conditions of the proposed technical solution are described. Here, we focus mainly on the thermal comfort in summer conditions because of high internal heat gains due to office work and the selected climate being mild, dry and sunny even during winter.

Thirdly, operating conditions of the proposed technical solution are described in exceptional situations. It aims at helping the owner and the operator to provide a safety strategy under thermal stress situation, means when it is too cold or too hot for occupants' health.

The presented work has some limits. It excludes carparks and retails from qualitative and quantitative approach. However, there are treated under a prescriptive point of view. Moreover, analysis of heat transfers and design of energetic technical solution are mostly conducted qualitatively with few numerical order built under static situation. Thanks to Provençal climate and strong internal heat gains, due to office activity, energy needs for heating are estimated very low. Thus, only hot situations are treated.

1.3 LOCAL CLIMATE IN AVIGNON

The Provençal climate is known to be mild and dry in winter and hot in summer. Avignon is at about hundred kilometers inland. Thus, in summer, temperature during day is hot while it may drop below fifteen at night. This amplitude is an opportunity for a high inertia building to keep comfortable inside environment on a thermal point of view. Indeed, heat stored in the day is removed at night thanks to outside fresh air crossing the building. In winter, solar and internal gains heat the building. The meteorological data used here are given by the French thermal regulation⁶.

Extreme annual weather data corresponding to summer and winter in Avignon are plotted on Figure 3. Outside temperature oscillate between 14 °C at night and 37 °C on the last week of July. In winter, in the fourth week of January, temperature reaches 11°C during day and drops under -4°C during night. These extreme periods do not exceed eight days. In Avignon, the average temperature for the year is around 15°C.

The degree day ("degrés jour unifiés" (DJU) in French) allows to estimate energy consumption relative to the severity of winter. In Avignon, the degree day is about 1600, while the average degree day in France is around 2500. The climate is consequently considered as mild in winter.

Based on these climatological data, solar gain is estimated. Figure 4 illustrates the distribution of solar radiation on a vertical plane with the orientation at both solstices and both equinoxes.

⁶ RT2012, <http://www.rt-batiment.fr/batiments-neufs/reglementation-thermique-2012/donnees-meteorologiques.html>

Radiation on a vertical plane does not exceed 800 W/m². The reflective contribution is not visible. On south side, because of water reflexion its contribution to radiation is little. But, on the east and more on the west, with high reflexion surfaces in surrounding area, global radiation on a vertical window can raise 900 W/m².

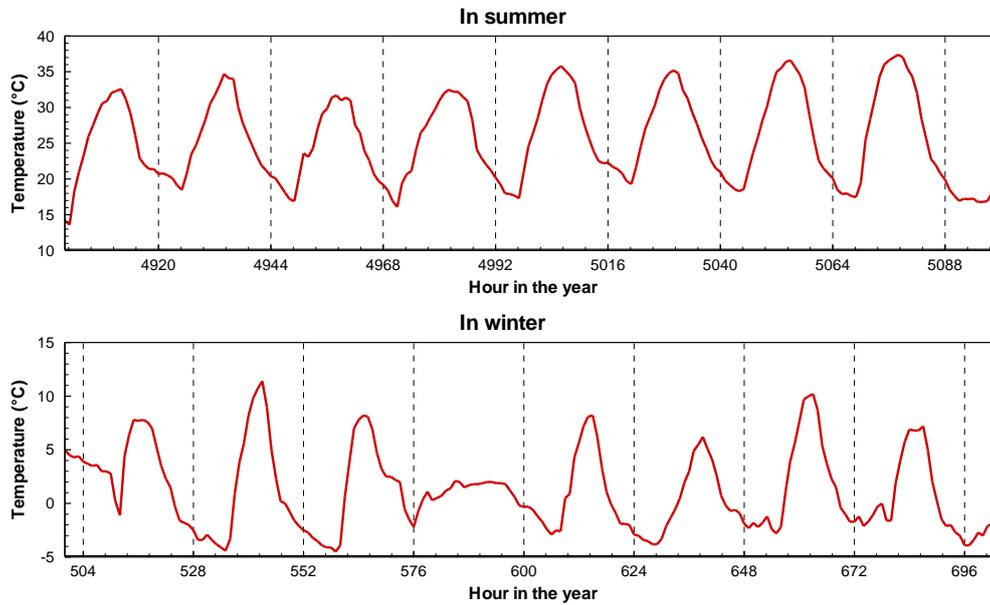


Figure 3: Outside temperature in summer and in winter

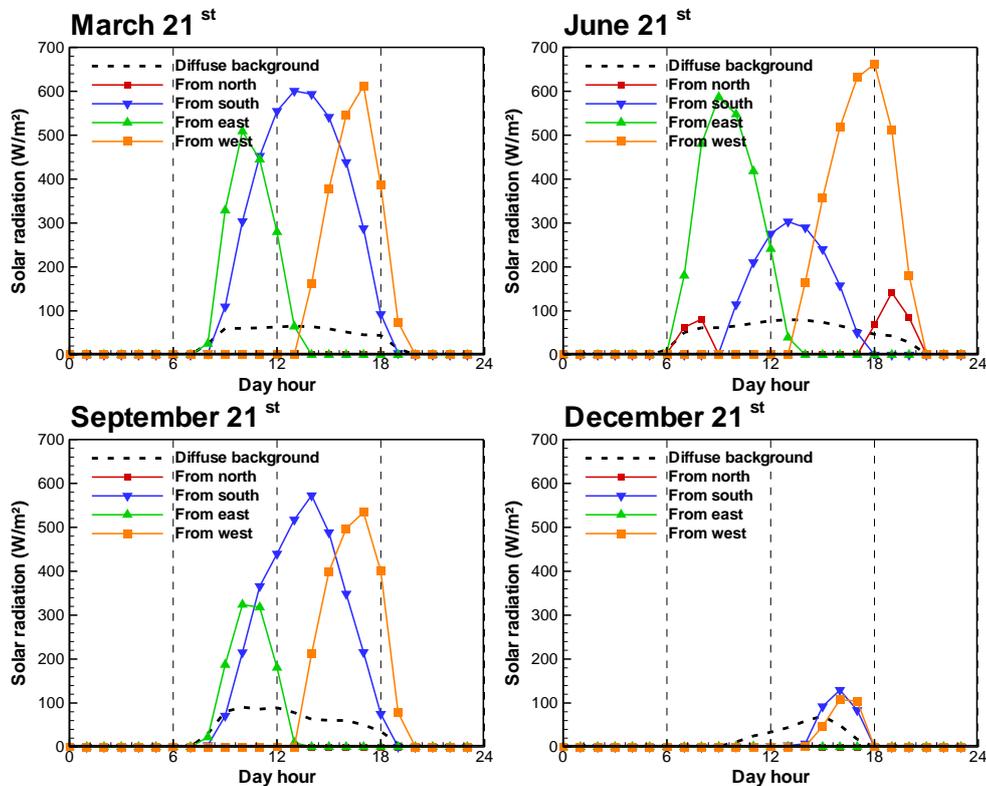


Figure 4: Distribution of solar gain with the orientation

1.4 INTERNAL LAYOUT, BUILDING OCCUPANCY AND HYGIENE

A consequence of the climate and our design guideline is that the glazed curtain walls choice for façade materials is extended to the façade on the north side. It is composed of two glass skins separated by an air layer. This technical solution contributes to ensure a natural lighting and does not present a strong increasing of heating demand thanks to mild winter, double glazing insulation performance and vacancy at night time.

In order to promote a sufficient air flow and to maximize natural lighting at each overall office level, we choose open workspaces. Consequently, there is a minimum number of dividing walls on each level which limit the natural aeraulic flow and create area of shadow. To complete the open workspaces, each office level has a 40 m² relaxation area (with coffee maker and a few tables) and two 40 m² bathroom facilities accessible to people with reduced mobility, a few meeting rooms are dispersed too. The IT unit and the network server room are included on level L4. The archives are placed on level L5 between a bathroom facility and the open stairway on the south side. Bathroom facilities, IT unit workspaces, the network server room and archives are enclosed. Outer meeting rooms are enclosed, the ones at a central position, within the open workspaces, are delimited by 3 m high walls to promote aeraulic flow in the 1 m high free space. Relaxation areas are opened on workspaces.

The case study building specifications set that the edges of the floor voids are separated by balustrades only and that no wall or bulkhead barriers are to be installed at these locations to enclose the voids. In this way, some workplaces are positioned directly along the floor voids for reasons of:

- Security: This configuration aims at avoiding someone drops an object through the floor voids. It could damage the equipment or even hurt people on the level below. With the balustrade, this configuration also provides an additional way to avoid people falling through the floor void.
- Privacy and confidentiality: The voids are staggered. This configuration allows to ensure a certain privacy for people on the level below by avoiding a vision from a higher level.
- Comfort: To improve comfort for workers (acoustic and air flow from the voids), a shutter is positioned between workplaces and floor voids. This shutter is 2 m high maximum to respect the case study building specifications.

Aisles are arranged on each office level in order to limit journey throughout the level, to be close to elevators and stairway, to allow an easy access to bathroom facilities, to be close to meeting rooms. Also, aisles are positioned along the open stairway on the south side and the facade on the north side. Aisles are distributed regularly on each office levels, to constitute a way between north and south sides. Aisles on the north side are considered as main aisles with 3.6 m wide. Close to floor voids, aisles are 4.0 m wide to provide enough space for storage. The other aisles are 1.4 m wide.

Finally, the following table summarizes our internal layout of the building which respects all case study specifications. In comparison, the following table gives the conventional distribution defined in the French thermal regulations.

		Final internal layout for the case study		Conventional distribution according to the French thermal regulations
		Surface area (m ²)	Percentage distribution	Percentage distribution
Total area		8960		100
Workspaces, IT unit and network server		4930		60
Aisles, Reception	Aisles	2339	2715	30
	Reception	376		
Meeting rooms		915		10
Bathroom facilities		400		4

Table 1 : Final internal layout of office levels and conventional distribution defined in the French thermal regulations

The building occupancy is defined based on usual conventions [3]. It is also recommended one workplace per 10 m² area. Moreover, it is recommended for meeting rooms, 15 m² for 8 people, 45 m² for 14 people, 90 m² for 20 people and 65 people in a 135 m² auditorium [29]. In practice, for the present case study, there are roughly 900 people in total at the office levels with 500 workspaces. On each level, there are between 122 and 290 persons maximum following the level internal layout and its surface area (cf. Table 2).

Level	Occupancy	Details	
		Activity	Occupancy
L4	160	Open workspaces	80
		Reception	40
		Two meeting rooms	20 each
L5	140	Open workspaces	100
		Two meeting rooms	20 each
L6	290	Open workspaces	120
		Conference room	150
		One meeting room	20
L7	190	Open workspaces	150
		Two meeting rooms	20 each
L8	122	Open workspaces	50
		Two meeting rooms	40 plus 32
Total	902		

Table 2: Building occupancy per office level

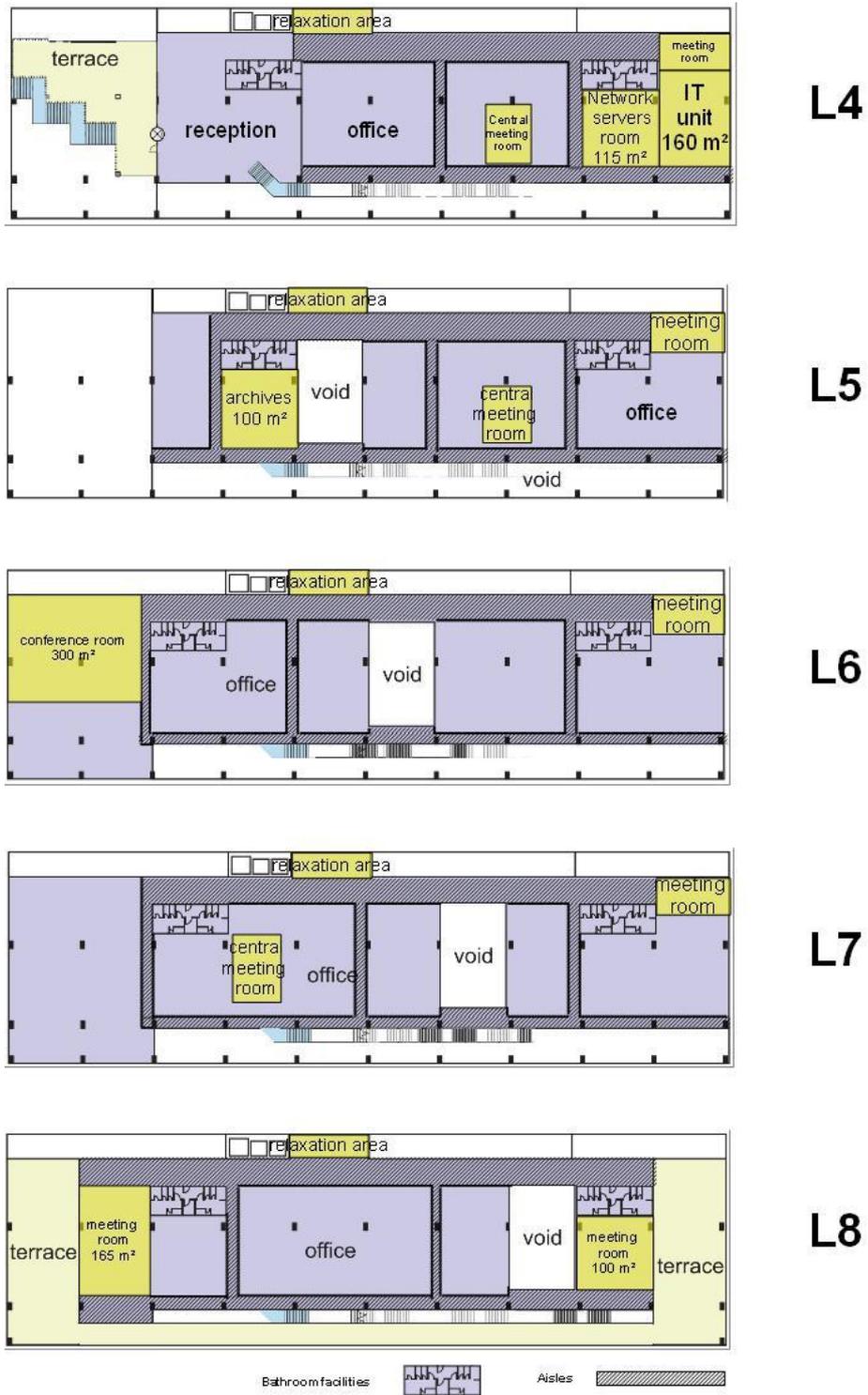


Figure 5: Outline sketch of internal layout on each office level

Ventilation for hygiene is to renew air within the buildings by extracting fouled air and supplying fresh air, by natural or mechanical means. Such ventilation works during the period of occupancy of the building and is turned off otherwise. Balanced type ventilation is preferred for heat recovery in winter. Indeed, with such technology, there is no need to heat the fresh incoming outdoor air. Heat exchanger is by passed during cooling period.

The exhaust flow rate is determined on the basis of the French Labor Code [5] which sets different recommendations following the activity:

- in workspaces, 25 m³/h per person i.e. 12500 m³/h for 500 workspaces,
- in meeting rooms, 30 m³/h per person i.e. 10 860 for 362 persons,
- in bathroom facilities, 195 m³/h per facility i.e. 1 950 m³/h.

Meeting rooms, bathroom facilities, the IT unit, the network server room and the archives are ventilated with specific systems. Open spaces composed of workspaces, relaxation areas, open stairways and the reception on L4 are ventilated simultaneously by the same mechanical system. Such system is thus designed to ventilate 14000 m³/h i.e. 0.55 Volume/h.

Level	Activity	Surface area (m ²)	Occupancy	Ventilation for hygiene (m ³ /h)
L4	reception	376	40	1 200
	workspace	784	80	2 000
L5	workspace	949	100	2 500
L6	workspace	1 177	120	3 000
L7	workspace	1 427	150	3 750
L8	workspace	573	60	1 500
Total		5 286	550	14 000

Table 3: Ventilation for hygiene on each office level

1.5 TECHNICAL SOLUTION TO PRESERVE THERMAL COMFORT

In order to insure thermal comfort during occupancy without any HVAC system, the building must, in one hand, use heat from its activities and from solar radiations, in the other hand, deals with thermal flow change during day. Thermal strategy differs according the season, whether it is hot or cold:

- Internal loads and solar radiation are used to heat inside environment. Ventilation is limited to hygiene and a balanced ventilation with a heat recovery system is used in order to minimize heat loss.
- Internal gains are limited thanks to efficient appliances, and solar gains are controlled using mobile solar protections whose allow diffuse daylight. Residual thermal load is supposed to be stored in the mass before to be evacuated by free cooling at night.

Thus, a double skin glazed façade with an integrated movable shading system is chosen as well as a heavy inertia structure.

In order to take advantage of thermal inertia of materials used in the ceiling construction, the floor construction and the floor finishes, it is necessary that these materials have a strong thermal effusivity thanks to a high conductivity and a high density, such as concrete. For instance, during hot weather, it allows that ceilings and floors store heat during the day due to internal gains (lighting, electronic devices, human activity) and sunlight and that, during the night, they release the accumulated heat thanks to the free cooling at night. Thus, ceilings and floors are considered made of concrete without any floor covering and continuous suspended ceiling. For acoustic comfort, lacks of floor covering like carpeting and continuous suspended ceilings are offset by an openwork acoustic suspended ceiling.

The façades on east, south, west and north side of the office levels are glazed curtain walls. Double skin façades are constituted of two double glazings separated by a cavity of air. Their use depends on the season (summer, winter) and time period during the day (hours of light, nights). It contributes to ensure a natural lighting. It can also increase radiant warming. The selected ventilation for comfort promotes a maximum use of natural air flow yielded by the thermal gradient between indoor air and outdoor air. It is based on openings in the double skin façade representing roughly 10 % of the total façade area following the French thermal regulations i.e. 400 m². Their openings are automatized. The principle consists in maintaining roughly the same indoor temperature in both summer and winter via the rotation of motorized integrated bands. It allows a ventilation or a natural warming within the building via the motorized bands [24]. With the goal to optimize the use of double skin façades and allows to get indoor conditions sufficiently comfortable (ambient temperature). The motorized bands are positioned on the four sides of the building on each office level in the lower part close to the ground and in the upper part close to the ceiling. Bands are operated independently on each level with a centralized opening and closing system controlled by the building energy management system (BEMS). This principle is deeply more detailed in the following section.

1.6 OPERATING CONDITIONS IN NORMAL USE

1.6.1 IN SUMMER CONDITIONS

In summer, during the day, the main goal is to conserve the most freshness accumulated during the night. For that, insulation capacity of double skin façades and strong thermal inertia of concrete present a great interest. In addition, high surface area of integrated bands contributes to nightcooling by releasing heat accumulated during the day.

During the day, heat from sunshine and internal heat gain (due to office activity) can be stocked partly or totally within concrete constituting ceilings, walls and floors. This phenomenon contributes to limit indoor temperature increase. Bands located on interior skins of the façades on the four sides are closed to insulate indoor environment from outdoor heat. Venetian blinds located between the two double glazings are put down on the four sides. Slats of the venetian blinds are tilted with the aims to decrease heat from sunshine and to diffuse natural lighting. Bands integrated in the exterior skin of the façades are opened (cf. Figure 6) in order to promote air circulation between the two skins and also limit greenhouse effect and corresponding indoor temperature increase. Bands integrated in the exterior skin on the other side are closed. Anyway they can be open if outdoor

temperature exceeds a set point which could be close to indoor one. This may occur if closed surrounding lead to a strong solar reflexion.

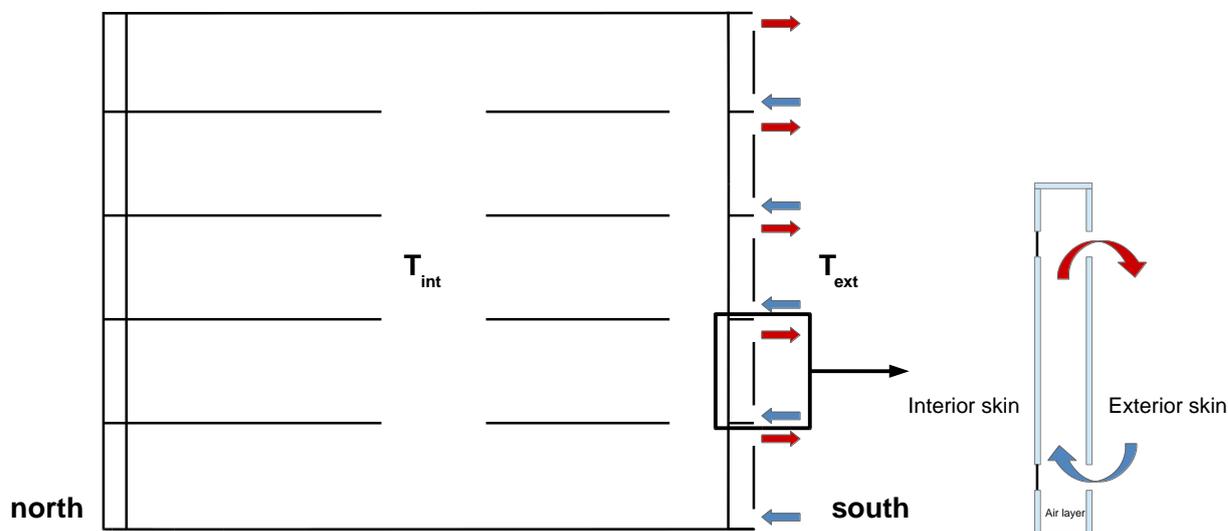


Figure 6: Openings state of bands integrated to exterior and interior façade skins during the day, in summer conditions

During the night, heat accumulated during the day is released by ventilating office levels with outdoor air, cooler than indoor air. To favor nightcooling, all bands located on both interior and exterior façade skins are opened, Venetian blinds are opened too. Relative to pressure difference, air flows through floor voids and open stairway on the south side from the bottom upwards or from the top downwards. Figure 7 illustrates predicted operating conditions.

During the week end, it is preferable to close down venetian blinds and to keep vertical their slats. Bands integrated in the exterior skin of the façades are opened. It may also be helpful to use free cooling at night whether inside temperature exceeds or not the referred comfort temperature.

1.6.2 IN WINTER CONDITIONS

In winter, there are two main goals during the day, limit heat loss and save heat from sunshine. During the night, it aims at conserving day heat gain.

During the day, the ideal process aims at ensuring warming by saving heat from sunshine and internal heat gain (due to office activity). In practice, indoor is not connected to outdoor for reasons of insulation. Interior façade skin on the south side is opened at the top and at the bottom when exterior skin is totally closed. Such openings allow to warm air circulating between the two skins with sunshine heat. Figure 8 illustrates predicted operating conditions. In addition, balanced ventilation installing for ensuring hygiene allows to recover heat from outgoing indoor air in order to warm fresh incoming outdoor air. To guarantee sufficient natural lighting and to optimize air warming with sunshine, Venetian blinds are opened on the four sides.

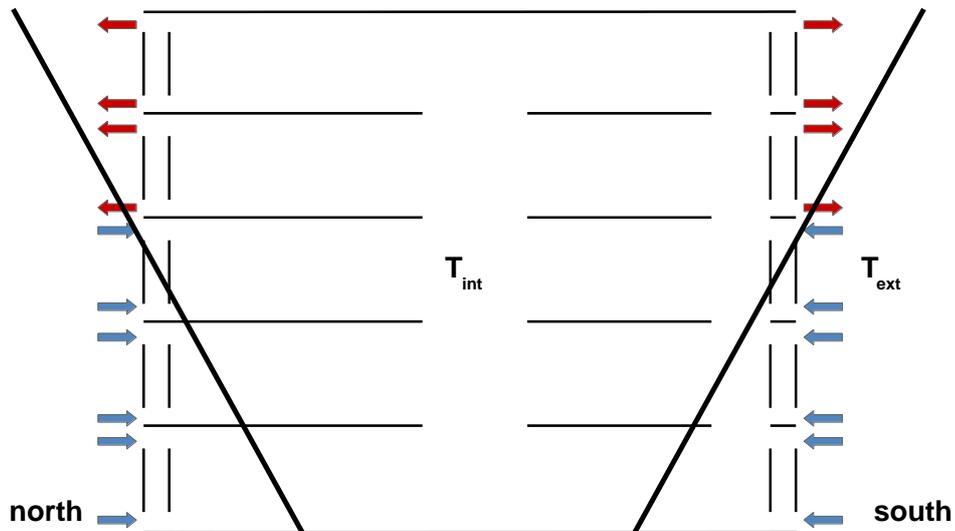


Figure 7: Openings state of bands integrated to exterior and interior façade skins during the night, in summer conditions

However, it appears necessary to install heating system in addition due to the occurrence of cold episodes during a few days at our latitudes, building occupancy variability, personnel being away for the weekend and during annual closure, etc. Thus, this system would not be necessary in the every-day operating conditions but rather in exceptional conditions due to climate or building occupancy. The question then is what size is needed and how to determine it.

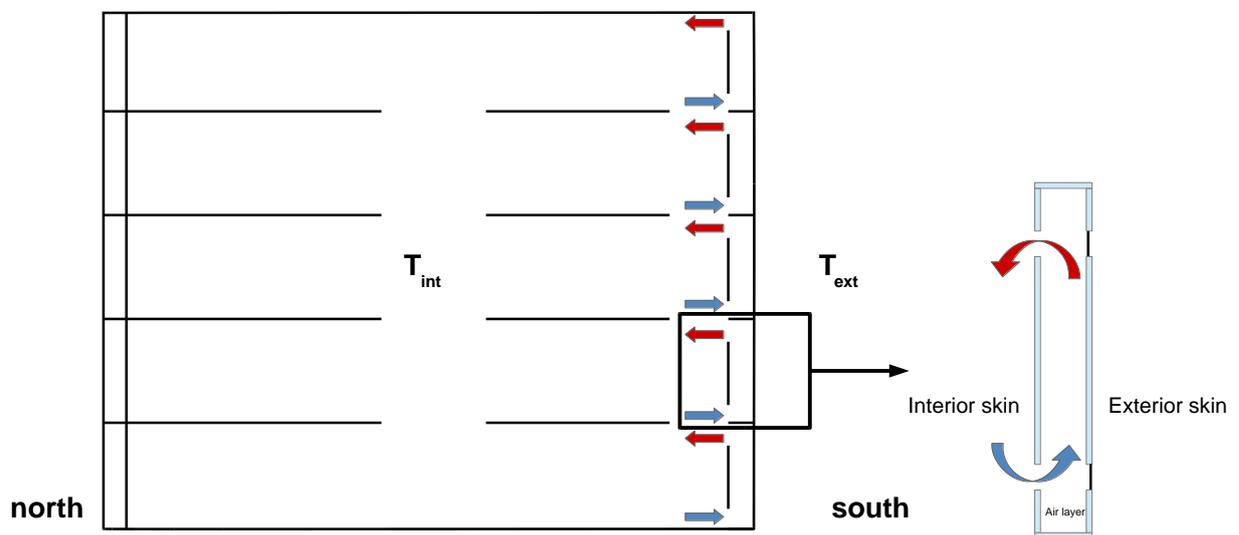


Figure 8: Openings state of bands integrated to exterior and interior façade skins during the day, in winter conditions

During the night, the process aims at limiting maximum heat loss to conserve day heat gain. Also, bands located on both interior and exterior skins of the façades on the four sides are closed to insulate indoor environment from outdoor coldness. Venetian blinds located between the two

double glazings are put down on the four sides too. Figure 9 illustrates predicted operating conditions.

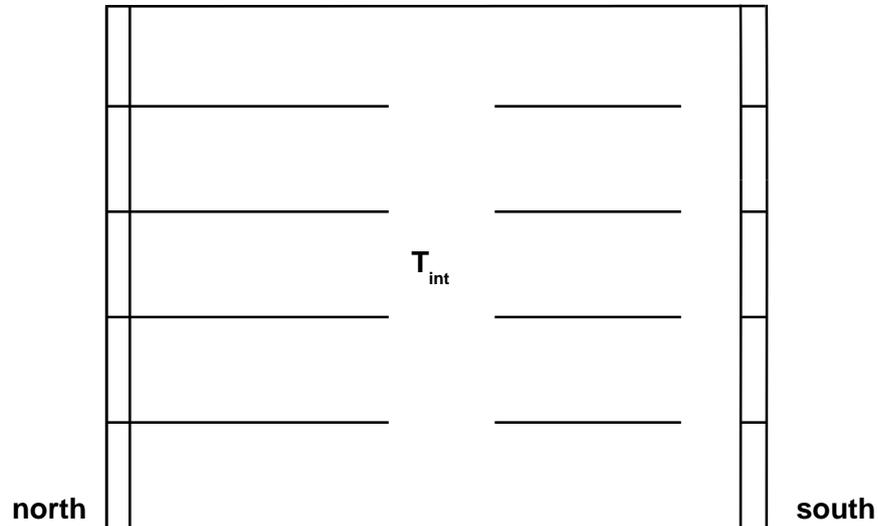


Figure 9: Openings state of bands integrated to exterior and interior façade skins during the night, in winter conditions

1.6.3 IN TRANSITIONAL PERIOD

There are two possible types of transitional periods. Firstly, outdoor air temperature can be higher than indoor air temperature which is lower than set point temperature. It occurs at the end of winter and/or after building inoccupation period for instance. Secondly, outdoor air temperature can be lower than indoor air temperature which is higher than set point temperature. It occurs at the end of summer for instance. In these two transitional periods, all bands located on both interior and exterior façade skins are opened with the aim to warm indoor air or to cold it.

In this first approach, because of huge voids in the building, equilibrium of pressures occurs at half of building height. But, it cannot be excluded that air flow crosses the air cavity of double skin façade which works like a heat exchanger thanks to greenhouse effect. Anyway in the first case, to warm the building it is even more efficient. *A contrario*, in the second situation, with the aim to cool the building, it is important to avoid double skin façade works as a heat exchanger. Thus if pressure difference is not strong enough to induce an indoor air flow through floor voids, it would be better to open bands only on north and east sides after noon or on west side in the morning.

Figure 10 and Figure 11 illustrate predicted operating conditions in both configurations.

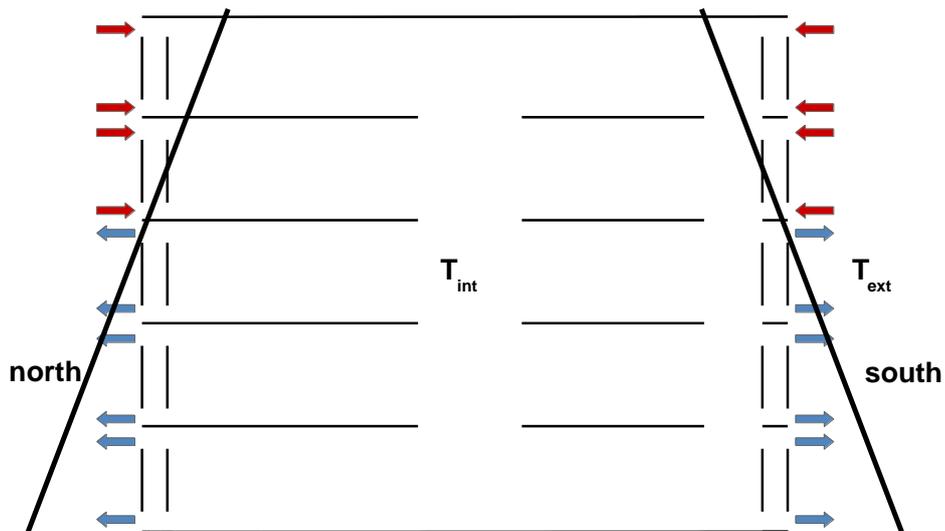


Figure 10: Openings state of bands integrated to exterior and interior façade skins in transitional period when outdoor air temperature is higher than indoor air temperature

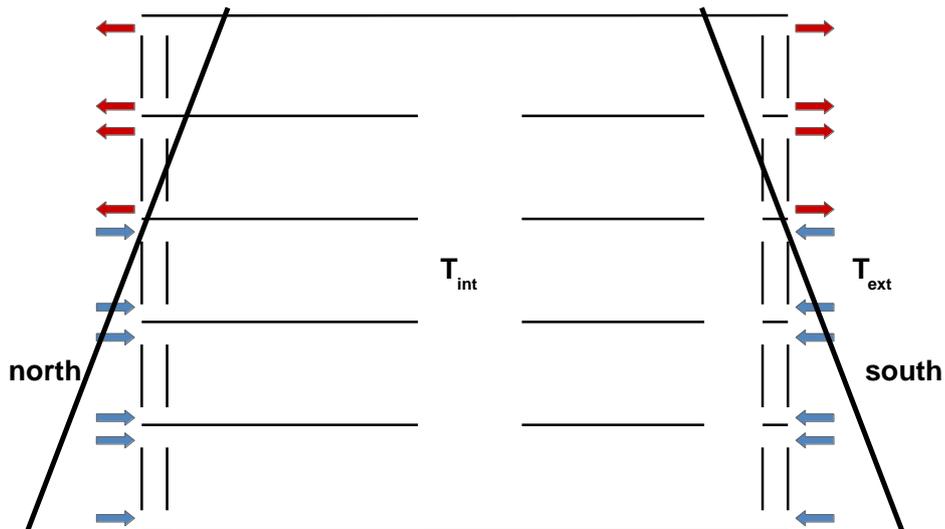


Figure 11: Openings state of bands integrated to exterior and interior façade skins in transitional period when indoor air temperature is higher than outdoor air temperature

1.7 WHEN DOES THE TECHNICAL SOLUTION WORK?

The qualitative description of the technical solution to preserve thermal comfort is attractive but does it really work? What are the limits of this technical solution? A few studies are dealing with this technology and a few building⁷ are equipped. However, the size of the system and its proper use require an overall study in which a building energy management system would be designed. Such

⁷ UE commission building « le Berlaymont », <http://www.energieplus-lesite.be/index.php?id=9748>

study is not conducted here. Anyway, the following numerical elements demonstrate project feasibility.

Firstly, summer is the season where internal heat gains are at their maximum. They are attributed to

- Human activity: 900 persons with a low physical activity of about 100 W [7730] lead to a heat gain of 90 000 W,
- Electronic devices: 550 computer workstations equipped with laptop PC and LCD screen lead to 50 W each in activity i.e. a total of about 25 000 W [9],
- Lighting is supposed around 10W/m² [10]. The corresponding total gain is 55 000 W,
- Additional internal gains for other electric appliances like computer servers, laser printers, may represent 10 000 W,
- Solar gain: The solar factor of double skin façade equipped with venetian blinds is supposed to be around 0.1, which is close to a double glazed window with an outside diffuse solar protection [11]. In summer, solar radiation in the afternoon represent 140 000 W power with such glazed surfaces and solar factor (200 W/m² from the east, 400 W/m² from the west, 500 W/m² from the south and 200 W/m² from the north),
- Incoming air: A ventilation system has been designed for hygiene in open spaces composed of workspaces, relaxation areas, open stairways and the reception on L4. It allows to ventilate 14000 m³/h. Thus, heat gains attributed to incoming air flow with indoor and outdoor temperatures equal to 37 C and 25°C respectively, is about 55 000 W.

During a 10-hour workday, solar heat fluctuates and lunch time interrupts human activity. Consecutively, internal heat gains may be lower than the strict addition of each contribution and would be around 375 kW. The corresponding total heat energy is 3 750 kWh.

Secondly, we considered ceilings and floors made of concrete without any floor covering and continuous suspended ceiling. Material ability to absorb heat (heat mass, exchange surface, surface coefficient of heat transfer) is estimated as follows:

1 m² of a 20 cm thick concrete slab can store 0.6 kWh/(m³.K). We suppose a density of 2200 kg/m³ and a 1000 J/(kg.K) specific heat capacity [12]. 1800 m³ of concrete correspond to heat storage capacity equal to 1080 kWh/K. Heat produced during the day, even in summer conditions with 3750 kWh, is capable to warm slabs up to 3.5 degree more. For instance, if slab is at 24°C at the beginning of the working day, its temperature at the end of day may rise up to 27.5 °C, which is a limit acceptable temperature.

In the case of hot days, free cooling is working during the night till outdoor temperature becomes below 25°C and then average outdoor temperature is about 20°C during a 11-hour night. Free cooling air flow is about 170 0000 m³ to evacuate 3750 kWh corresponding to 7-degree temperature difference. In other words, it represents 140 000 m³/h during 11 hours or about 3 volume/h.

What could happen in a critical time?

At, the hottest time in the day, there is a 375 kW heat emission inside the building. By considering heat transfer coefficient equal to $6 \text{ W}/(\text{m}^2 \cdot \text{K})$ [12] and slab surface for heat absorption of $18\,000 \text{ m}^2$, the slab capability to absorb heat is 108 kW/K . For a 3 degree temperature difference, slab can absorb 324 kW. Also, 51kW excess heat due to human activity and solar gain induce indoor air warming. For a volume of nearly $50\,000 \text{ m}^3$, air temperature increases of 3 degrees. Is inside temperature higher than 25°C before, this situation may lead to an uncomfortable environment with a temperature other 28°C . Also, the hottest time in the day occurs after 6 hours of occupancy when already heat has been stored in slabs during the past 6 hours and warmed the air. In this situation it would be better to begin the day with a lower inside temperature. It may be possible, but free cooling should work during the night till outdoor temperature becomes below 20°C and then average outdoor temperature is about 18.4°C during a 7-hour night. Free cooling air flow is about $175\,000 \text{ m}^3$ to evacuate 3750 kWh corresponding to 9-degree temperature difference. In other words, it represents $130\,000 \text{ m}^3/\text{h}$ during 10 hours or about 3.5 volume/h.

These values show that it is possible to get comfort with the proposed technical solution. However, to meet this objective, a particular attention should be paid to improve heat exchange between air and concrete slabs and to adapt air flow during night depending on heat gains.

This conclusion results from an estimation under standard occupancy and normal climate. So, we can wonder how indoor conditions would vary in incurrent situations.

The building owner can of course install an HVAC system. The issue is then to estimate the necessary engine power. Its design considers the possible stress situations and their occurrence. Also, with the aims to secure the building and to maintain its activities, it is necessary to imagine risk scenarios and corrective measures. The owner choice is motivated by the occurrence of risk scenarios, their possible intensity and their potential consequences. The choice is not only a technical matter but also raise questions about activity. Indeed, for instance, the choice could restrain occupancy, limit or even stop activity. In that case, the owner must assess when to take the decision and estimate the corresponding lost cost.

In this building, if outdoor air temperature exceeds 20°C during two successive working days and two nights, it will be difficult to keep an indoor temperature below 26°C . A solution to preserve comfort may be to promote convective exchange by increasing air speed in the person surroundings. It would be ensure with fans.

More occupants would lead to increase internal heat gains and thus air flow even during the day. Such flow increase would be ensured by opening additional exterior and interior bands. Do these alternative operating conditions have an impact on other risks such as fire safety? Is it an opportunity to limit fire risks or does it increase it?

2. HYPOTHESIS FOR THE PERFORMANCE-BASED FIRE SAFETY STUDY

2.1 APPROACH

The French regulation has permitted performance-based approach just recently, since 2004, to design smoke exhaust system and structure resistant to fire. Our work in this case study is deeply inspired by the French Fire codes and reflects our recent practice and our usual approach in fire safety. In practice, we looked to propose an alternative to a 100% sprinkler protection of the building by focusing instead on the following:

1. Structural characteristics of a modern, energy efficient and green building
2. Evacuation routes and smoke management with provisions for people with disabilities.
3. Fire safety organization and human response by occupants and fire brigades.
4. Evaluation of this strategy and comparison with other alternative strategies.

The performance-based fire safety study is conducted with a deterministic approach constituting of ten stages. It is summarized on Figure 12.

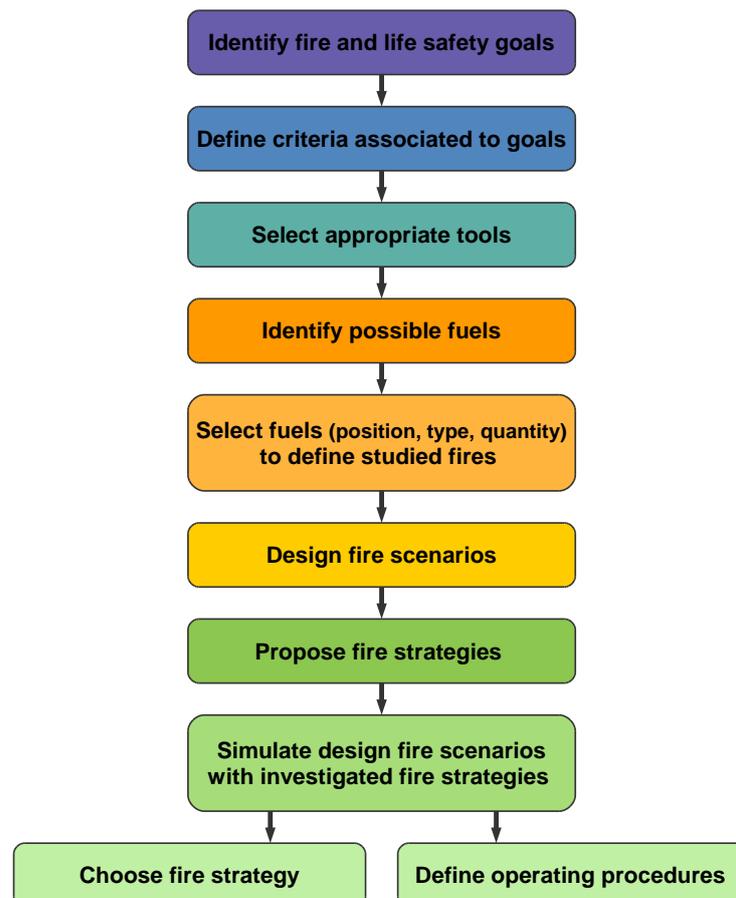


Figure 12: Our approach in the performance-based fire safety study

Since, it is a performance-based study, fire and life safety goals need to be identified by wondering to what we want to protect and what we expect. To assess if each goal is met, criteria are associated to each goal. These criteria correspond to physical quantities with thresholds. Then, tools are selected following their capability for the present case study i.e. the goals of the study, the building geometry and its dimensions.

To define scenarios, the fuels located within the building are referenced. Based on this list, the studied fires are defined. The selection is effected in order to choose fires which reflect a real configuration, vary sufficiently to not favor any strategy more than one other and be susceptible to conduct to a constraining situation. In practice, a fire is defined by setting a geometry, the maximum heat release rate, a growth rate and a heat capacity per unit area. When fires are selected, design fire scenarios may vary the place and the safety measures to assess their respective influence. For instance, the opening state of integrated bands dedicated to comfort ventilation varies.

Three fire safety strategies are proposed, each one being characterized by specific structural, organizational and technical aspects. To assess each of them, design fire scenarios are simulated with the tool and criteria are looked attentively. Last, the best strategy is chosen. The performance of the resulting strategy is assessed and corresponding operating procedures are defined in order to address fire and life safety goals.

Comment: The performance-based fire safety study has been conducted at the office level scale and not at the building scale, due to the insufficient human resources implied in the present study. Carparks and retails areas on levels L1 to L3 are dealt with a prescriptive approach based on French building standards.

2.2 GOALS

The fire and life safety goals are set following both the case study building specifications and the French building standards:

- Safeguard occupants and staff from injury due to fire until they reach a safe place.
- To meet this objective, we define a series of measures to favor people to safely and quickly leave the building or let them to reach a safe place.
- Safeguard fire fighters while performing rescue operations or attacking the fire.
- To meet this objective, we design the building structure in order to guarantee a fire resistance compatible with the delay time and the operation duration of fire brigades
- Design to avoid structural failure in the event of fire.
- To meet this objective, we design the building structure in order to guarantee a fire resistance compatible with fire duration.
- Design to avoid building-to-building fire spread. The east facade of the building being located within 1 m of the site boundary, it can be considered that a building is located at this distance. This proximity could contribute to fire propagation from one building to the other. To meet this objective, we must design a double skin façade resistant to fire.

2.3 CRITERIA ASSOCIATED TO GOALS

The French building standard proposes usual criteria to consider an environment safe for people:

- the free smoke layer is considered sufficiently high for evacuation when it is higher than 1.80 m from the elevation where people are,
- the heat fluxes are tenable for people (radiative fluxes and air temperature).

In most of configurations, the environment is stratified due to a gas temperature gradient along the vertical axis. There is also an upper layer of dark and hot smoke and a lower layer of transparent and fresh air. Based on this stratification, in most cases, consider the conditions compatible with egress or not is often based on thresholds associated to performance criteria (free smoke layer, tenable heat fluxes).

However, in the present case study, the large building dimensions and the interconnection between levels by floor voids contribute to smoke dilution and thus to low smoke temperature. In such situations, heat fluxes remain tenable in most cases. Moreover, it is arduous to deduce a thermal stratification height. Based on this analysis, it is necessary to define other criteria to assess if the goals are reached.

For goal 1 relative to occupants, the selected criteria describe the thermal and optical environment with mainly gas temperature and extinction coefficient. Indeed, due to the strong smoke dilution, gas temperature would likely not be sufficient to establish the presence of smoke. Also, the extinction coefficient appears appropriate since it traduces the capacity of the medium to attenuate light and also the degree of obscuration. Moreover, in the scientific literature, empirical relations associate extinction coefficient to distance of visibility [16]. We define stationary threshold: 50 °C for gas temperature and 0.2 for extinction coefficient (corresponding to 15 m for a light-reflecting sign and 40 m for a light-emitting sign). Criteria are satisfied and goal is reached when the conditions remain below these thresholds at 2.00 m higher than the elevation where people are. There is no criterion relative to toxicity since we estimate there are too many questions (chosen fuel, effect on an individual) which raise doubts about its relevance.

For goal 2 relative to safeguard fire fighters, the selected criteria describe the thermal environment with mainly gas temperature. We define a stationary threshold, 80 °C. Moreover, for the safeguard fire fighters, we are concerned on the structural fire resistance to avoid its collapse during their operation. Also, it meets the goal 3.

For goal 3 relative to structural failure in the event of fire, we apply the French building standards and suppose it is performing. Thus, there is no criterion relative fire resistance.

For goal 4 relative to building-to-building fire spread, we look at the thermal conditions capable to induce double skin façade failure first and then to lead fire spread via flame radiative heat and hot smoke plume. The considered criterion is temperature with threshold of at least 200 °C [13].

2.4 USED SOFTWARE, COMPUTATIONAL DOMAIN AND OUTPUT DATA

2.4.1 ASPECT RELATED TO SMOKE FILLING

For simulating smoke filling, CFD code is preferred in comparison with zone models. This choice is motivated by the large building dimensions and the interconnections between levels. Indeed, the strong dilution induces low smoke temperature and thus, smoke and fresh air do not constitute layers clearly separated. The present work makes use of the Fire Dynamics Simulator (FDS, developed by NIST, USA [20] [21]). This numerical tool is a 3D CFD model designed to simulate low-speed, thermally-driven flows. It is widely employed in the fire community, generally in order to evaluate fire consequences in buildings. Thus, it profits of an important experience feedback. Ref. [22] gives an overview of FDS validation cases conducted in the last decades, in particular, for compartment fires and fire plumes. Otherwise, FDS has shown good capability to predict gas velocity, temperature and concentrations at various detector locations. Moreover, “FDS is capable of predicting smoke detector activation when used with smoke detector lag correlations that correct for the time delay associated with smoke having to penetrate the detector housing.” [22].

The building internal layout presented previously is respected. It is reproduced with cubic grid cells of 50 cm×50 cm×25 cm. A sensitivity analysis of grid size has been undertaken with two finer grid spacing (25 cm×25 cm×25 cm and 50 cm×25 cm×25 cm) and one bigger grid spacing (1 m×50 cm×25 cm). The computational time is of 35 h, 79 h, 170 h and 427 h, from the biggest to the finest grid mesh. The flow rate (in volume and in mass) of smoke evacuated via the bands integrated to the façades is identical in an overlap of 6 % between the two extreme meshes.

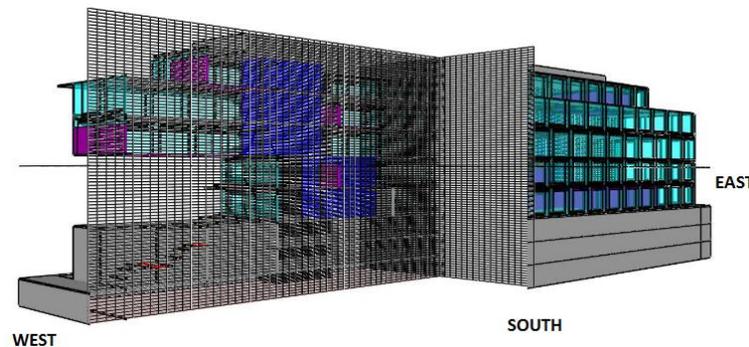


Figure 13 : Building reproduced computationally for FDS calculations

Thermal properties for boundaries represent the used materials for ceilings, floors and façades. Floors and ceiling are also made of concrete rather than walls are made of glass. Their characteristics are listed in Table 4.

Materials	Density (kg/m ³)	Conductivity (W/m.K)	Specific heat (kJ/kg/K)	Emissivity	Thickness (m)
Concrete	2230	1.75	1	0.9	0.2
Glass	2200	0.9	1	0.9	0.05

Table 4: Characteristics of material for building ceilings, floors and façades

To assess the conditions relative to the criteria defined in the previous section, the output data in the simulations are gas temperature and light extinction coefficient deduced from the density of smoke particulate. These data are extracted on planes in the computational domain. Planes are either horizontal at 2 m high from each office level floor (cf. Figure 14), or vertical along the longitudinal aisles on north and south side (cf. Figure 15).

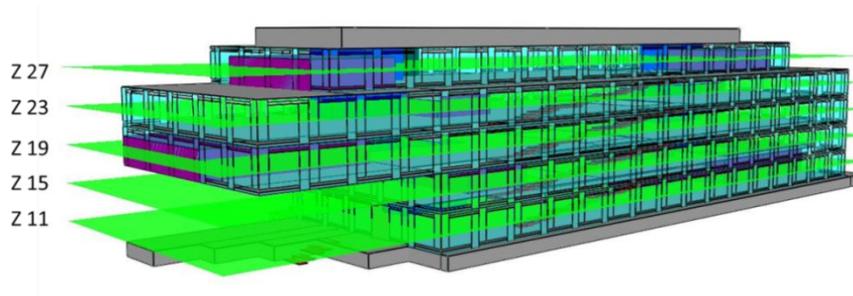


Figure 14 : Horizontal planes for outputs from FDS code

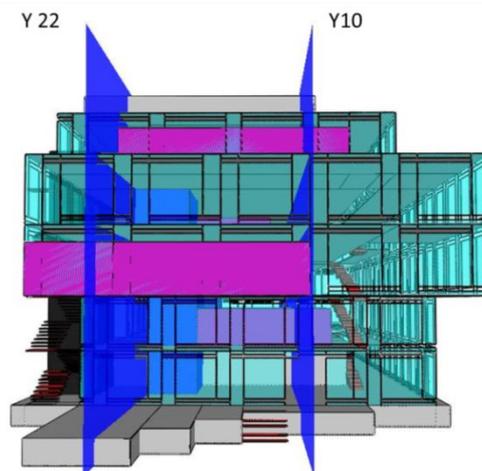


Figure 15: Vertical planes for outputs from FDS code

2.4.2 ASPECT RELATED TO FIRE PROPAGATION VIA THE FAÇADES

To study building-to-building fire spread, we look at the thermal conditions capable to induce double skin façade failure first and then to lead fire spread via flame radiative heat and hot smoke plume. In that frame, the study is based on the use FDS code.

2.4.3 ASPECT RELATED TO PEOPLE EVACUATION

Evacuation is simulated with the code SEVE-P which has been developed at CSTB [28]. This code is dedicated to buildings with high occupant density where individual compartment and decisions do not yield the total time for evacuating:

“the greater the flow density is, the less of freedom there is” [25].

The model is based on a spatial discretization of the building floor surface composed in squares of uniform size. Mesh grid is adapted to each building following its size and the shape of obstructions (walls, internal layout, voids).

The model supposes an occupancy varying with time. Occupants are tracked individually. At each time step, his position is known. Each occupant looks like a circle characterized by its center position and its radius. The center position indicates the occupant position. Its radius represents the surface area of horizontal projection of occupant calculated in function of the occupant age, his clothes, etc.. Each occupant is susceptible to occupy every unfilled grid cell.

Occupant movement is yielded by the determination of optimum way. To determine it, the approach consists in drawing tree-view which relates each exit to every grid cell. Occupants do not follow strictly this tree-view, they aim for its final destination (fire exit) by following the way. Also, an occupant reaches the final destination, step by step, with fluctuations induced by occupant density variation. These fluctuations can even make him make the choice to follow an other path in the tree-view to reach an exit.

Speed of occupant movement varies with occupant density following empirical formula established by Predtechenskii and Milinskii [25]. At each time step, for every occupant, his movement speed is calculated in function of the occupant movement direction, the local density in this direction and the degree of intensity of the process. Formula from Predtechenskii and Milinskii has also been extended: formula valuable for high density flow moving linearly in one direction are applied locally at the scale of the occupant environment.

In the present case study, the five following assumptions are made in the simulations.

(1) We consider 290 persons on level L6, its maximum occupant density. This level is selected since, it combines open workspaces and meeting rooms and it is where the number of occupants is the highest.

(2) In case of fire, people being evacuating have to make a choice concerning the evacuation way. Three cases are simulated. Firstly, people evacuate by his closest stairway, the three stairways are available. Secondly, people evacuate by the two enclosed stairways on the north side. Thirdly, people evacuate by only one enclosed stairway on the north side. It allows to assess the influence of the number of available exits.

(3) The time required to detect the fire, locate the fire and dispel any doubt is neglected. People evacuate as soon as the calculation begins. Human behavior is not represented.

(4) The evacuation time is supposed to be the time to cross the exit door between workspace and stairway. Only door dimensions condition the time to evacuate. We do not consider the impact of crowded stairways for instance.

(5) Fire effect on people and more particularly on their speed is not taken into account.

(6) We consider two cases, firstly with free spaces and secondly with furnished workspaces. These two cases allow to assess the influence of the internal layout on time duration for people evacuation. The unfurnished configuration allows to estimate the occupant egress time depending only on the size of access doors, their position and the number of available doors.

To assess the time period necessary to evacuate people from level L6, we need to know first where people are susceptible to be at the initial time, by which way they can evacuate, what could constitute an obstacle to their egress. In that frame, we need to determine clearly every activity area, the main obstacles to egress due to building (walls, balustrades), the possible stairways and the doors.

On level L6, people are likely to be situated in workspaces or in meeting rooms including conference room (cf. Figure 16). To evacuate, there are three possibilities (cf. Section 3.4). There is the open stairway on the south side. Two additional stairways are positioned on the north side at two distant positions too. Each stairway is accessible by one 2.4 m wide way and doors (cf. Figure 16). Obstacles for people are the walls (building, bathroom facilities and meeting rooms) and the balustrades along the floor voids.

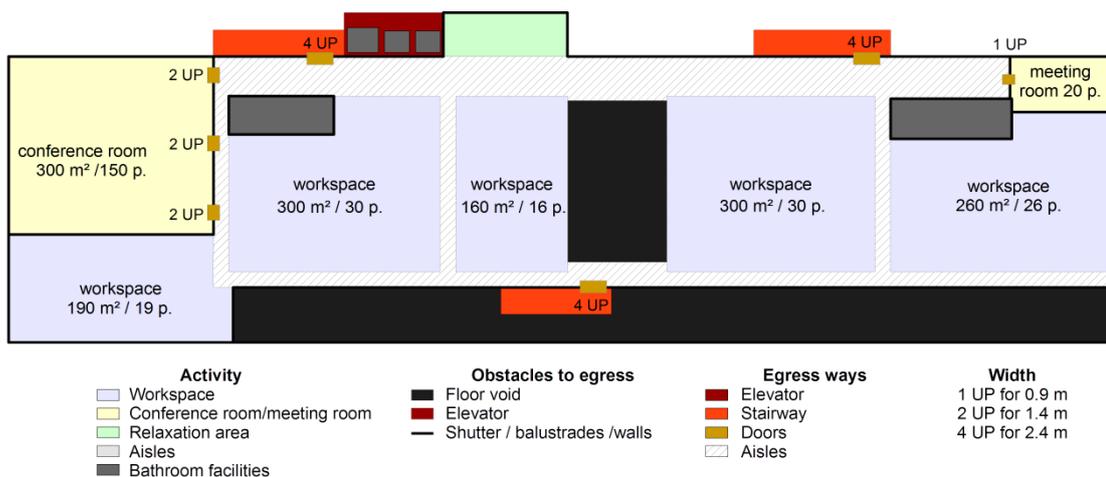


Figure 16: Activity, main obstacles and stairways on level L6

As it is reasonably foreseeable, there are other obstacles to egress due to the activity within the building. Indeed, levels L4 to L8 are intended for office activities that is to say typical office furniture and electronic equipment would be necessary. Also, on level L6, we arrange furniture by following the usual conventions which recommend one workplace per 10 m² area [3]. We aim at providing per person one desk (3 m long and 0.5 m wide), one upholstered chairs, one large storage cabinet (2 m long, 0.5 m wide and 2.5 m high) and one small storage cabinet (1 m long, 0.5 m wide and 1 m high). Furniture is arranged in two manners, either one workspace is isolated or workspaces are placed side by side. Shutters separate individual workplaces in order to improve privacy and comfort, they are 2 m high maximum (cf. Section 1.4). Figure 17 illustrates an example of furnished workspaces following these principles.

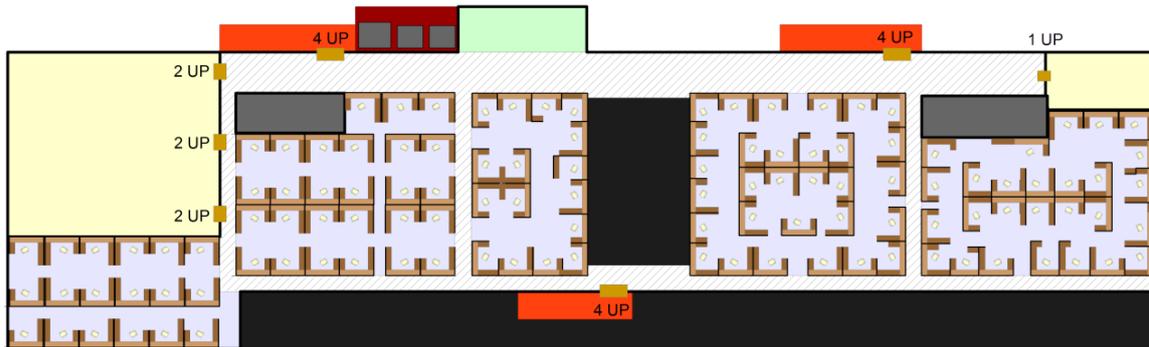


Figure 17: Furnished workspaces on level L6

In the present study, we estimate the time duration necessary to people evacuation in two situations, firstly with free spaces and secondly in furnished workspaces. In practice, two computational domains are consequently used. In the first domain, people are distributed following building occupancy in workspaces and meeting rooms. (cf. Figure 18, people are presented by red points). In the second domain, obstacles are placed to respect globally the proposed internal layout and people are placed at their location during their activity (cf. Figure 19, people are presented by red points and obstructions by brown squares). On the next two figures, doors are symbolized by green squares.

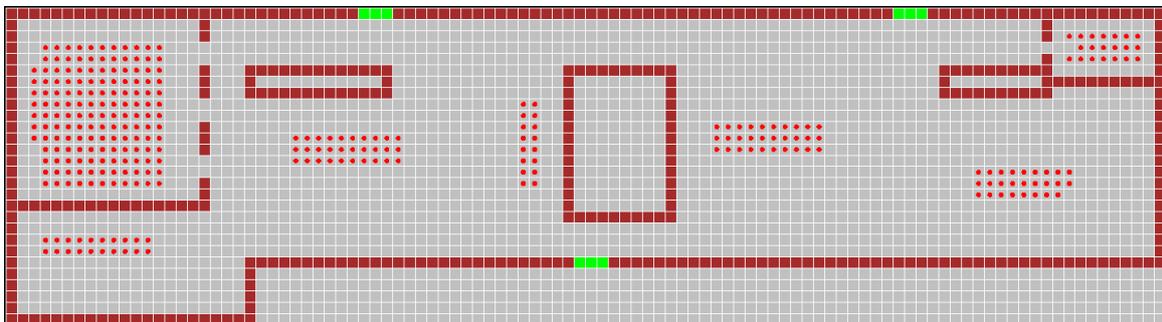


Figure 18: Computational domain for unfurnished workspaces on level L6

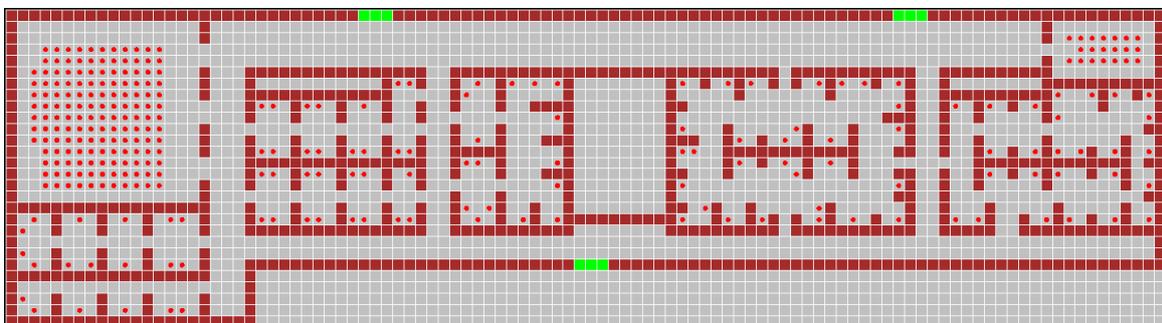


Figure 19: Computational domain for furnished workspaces on level L6

2.5 DESIGN FIRE SCENARIOS

In the present case study, the following parameters should be considered in scenarios:

- The place
 - The opening state of integrated bands dedicated to comfort ventilation: each band can be open or closed independently,
 - The indoor air temperature relative to outdoor value which can cause natural aerulic flow in the overall building from top to bottom or the reverse,
 - The climatic conditions (wind, ambient temperature) which can influence notably the efficiency of natural ventilations,
- The fuel
 - Its type, its quantity and its geometry which influence heat release rate and smoke filling,
 - The location of the fire (open workspaces, meeting rooms, IT unit and network server room, archives) in the building, on the concerned level, relative to the floor void, relative to the open stairway, etc. The fuel position must reflect a real configuration and vary sufficiently to not favor any strategy more than one other,
- The safety measures
 - The opening state of each floor void (open, closed),
 - The presence of smoke barriers along the open stairway on the south side and along each level interconnection,
 - The activation of all safety measures in the simulation or only some, for instance located at the fire concerned level,
 - The time duration before the activation of safety measures (the exhaust ventilation system).

However, to assess the interest of each of this parameter, we would need to propose a huge number of studied scenarios (at least many dozens). It is not conceivable to study all of them since it is not compatible to performance-based study with a deterministic approach. Finally, we define thirty-five scenarios by giving priority to some parameters, considered as the most influent.

2.5.1 IDENTIFICATION OF POSSIBLE FUELS

To define the studied scenarios for performance-based study, the fuels located within the building are first referenced. We look at identifying the ones susceptible to burn due to their nature or their position and we select the one enable to conduct to a constraining situation.

For ensuring office activities, they are different spaces from L4 to L8. All are identified on Figure 5. The reception with the IT unit and the network server room are on level L4. The archives are placed on level L5. Each office level includes two bathroom facilities accessible to people with reduced mobility, a 40 m² relaxation area, open workspaces and a few meeting rooms.

In the every-day conditions, the reception on level L4 is dedicated to welcome visitors. It contains desks, upholstered chairs and electronic equipment for IT, printing and telephony (including fax machines). The reception may contain shelves, sofas and coffee tables for visitors. Exceptionally, the reception can be decorated, for instance with a Christmas tree at Christmas.

The IT unit and the network server room are on level L4 (cf. Figure 5). They contain desks, upholstered chairs, electronic equipment and storage bays for servers.

The archives on level L5 contain all the documents produced by the bank. Due to their type of activity, they are closed and isolated from the rest of L4/L5 by walls resistant to fire. In addition, a fixed firefighting system could be installed in such specific hazard spaces (cf. Section 3.3).

Open workspaces on each level (designated by the term “office” on Figure 5) contains typical office furniture i.e. desks, upholstered chairs and electronic equipment. Furniture is arranged in two manners, either one workspace is isolated or workspaces are placed side by side.

In relaxation area (designated by the term “relaxation area” on Figure 5), we suppose there are two coffee machines, two drink and snack dispensers, three tables and about fifteen chairs.

Meeting rooms (designated by the term “meeting room” on Figure 5) contain tables and chairs. Their number differs with the capacity of the meeting room. In the conference room, the meeting room where the most people can be present, the firm could host reception exceptionally.

Along the edges of the floor voids, in storage spaces, are positioned photocopy machines with storage cabinet and reams.

2.5.2 POSITION AND TYPE OF SELECTED FUELS

Among the thirty-five scenarios, seven different fires are involved by varying heat release rate, fire surface area, fire location in the building and fire location on the concerned level relative to floor void, open stairway and aisles dedicated to evacuation. For each scenario, its parameters are detailed in Table 5.

- Concerning the fuel type, the choice is motivated by the fuel representativeness within the building and its likelihood to burn. Moreover, we retain only fuels positioned in unenclosed spaces. Indeed, specific strategy will be proposed for specific hazard spaces (cf. Section 3.3). We retain three types of fuels fire involving
 - office furniture (desk, storage cabinets and upholstered chairs) ,
 - machine, storage cabinet and reams,
 - coffee machines or drink and snack dispensers.

To each fuel type, correspond a surface area, a mass quantity and a quantity of heat released by fire per unit area. The determination of these parameters is based on the scientific literature, it is detailed in the following section.

- Concerning the fire location in the building, fires are simulated at each office level except on level L8. Indeed, this level is considered as the less constraining for building smoke filling and thus the easiest to control whatever the selected strategy.
- Concerning the fire location on a level relative to floor void, open stairway and aisles dedicated to evacuation, the fire position must reflect a real configuration and vary sufficiently to not favor any strategy more than one other. Fire are positioned
 - close to a structural column in order to conduct the performance-based study in fire resistance,
 - at different distances (close or far) from floor voids and open stairway. It allows to assess the capability of the fire strategy to control smoke movement and let levels free of smoke (level where the fire is located, levels below, levels above),
 - close to aisles and exits which could be used for evacuation,
 - close to façade in order to estimate maximum value of heat incident to wall and also study potential façade damage that could contribute to fire propagation to other levels or neighboring buildings

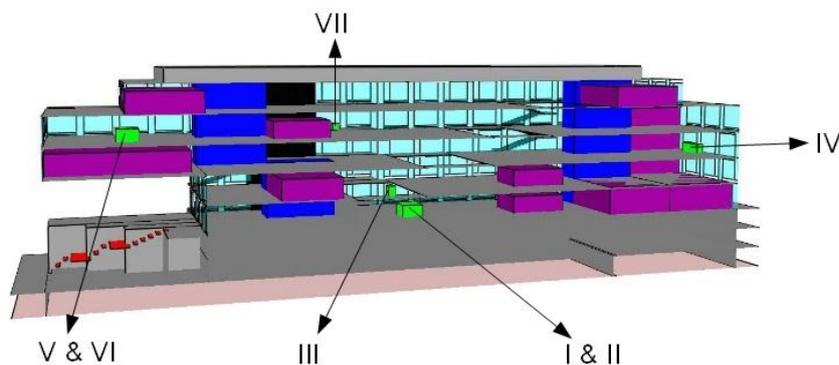


Figure 20: Location of the seven fires considered

2.5.2.1 Level L4

Two fires are simulated on level L4. Both involve office furniture (desk, storage cabinets and upholstered chairs). One is localized (10.25 m² surface area), the other is three times vaster. They are located close to a structural column. They are close to open stairway and floor void between L4 and L5 too.

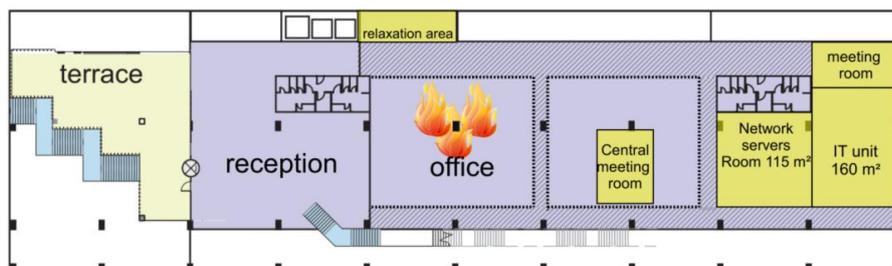


Figure 21: Fire locations on level L4

Studied fire	Level	Implied fuel	Location	Growth rate	Maximum HRR	Surface area
I	L4	office furniture	close to floor voids and open stairway	- slow till 200 s - medium between 200 and 600 s	3 MW	10.25 m ²
II	L4	office furniture	close to a structural column	- slow till 600 s - medium between 600 and 1300 s	9 MW	30 m ²
III	L5	photocopy machine, storage cabinet and reams	close to floor voids and open stairway	fast	1.5 MW	7 m ²
IV	L6	office furniture	close to the façade WEST	- slow till 600 s - medium between 600 and 1300 s	9 MW	30 m ²
V	L7	office furniture	in the workspace situated at west side	- slow till 200 s - medium between 200 and 600 s	3 MW	10.25 m ²
VI	L7	office furniture		- slow till 600 s - medium between 600 and 1300 s	9 MW	30 m ²
VII	L7	coffee machines, drink/snack dispensers in relaxation area	close to one of the stairways dedicated to evacuation	medium	1.5 MW	5 m ²

Table 5: Summary of position and type of selected fuels

2.5.2.2 Level L5

One fire is simulated on level L5. It involves photocopy machine, storage cabinet and reams. It is positioned in storage space along the floor void between L5 and L6. Fire is positioned close to the open stairway on the south side.

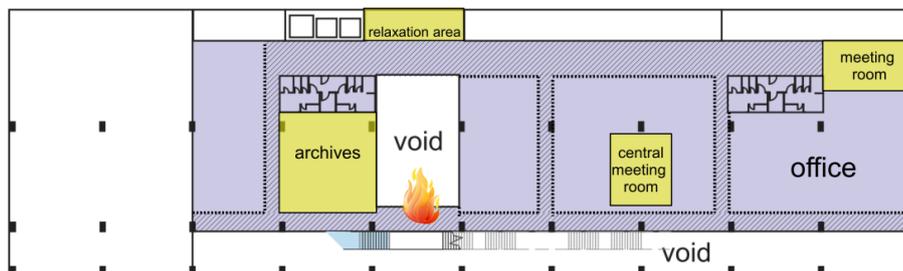


Figure 22: Fire location on level L5

2.5.2.3 Level L6

One fire is simulated on level L6. It involves office furniture (desk, storage cabinets and upholstered chairs). It is positioned close to the façade. This fire is vast and its heat release rate is very high.

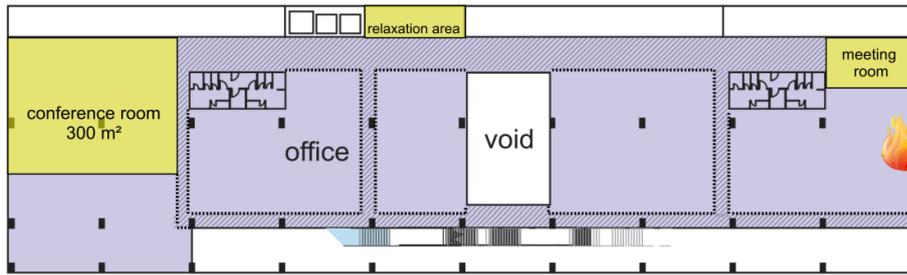


Figure 23 : Fire location on level L6

2.5.2.4 Level L7

Three fires are simulated on level L7. One fire involves coffee machines and drink/snack dispensers in the relaxation area, on the north side. This fire is located close to one of the three stairways dedicated to evacuation. Two other fires involve office furniture (desk, storage cabinets and upholstered chairs) both in the workspace situated on the west side. One fire is localized (10.25 m² surface area), the other is three times vaster.

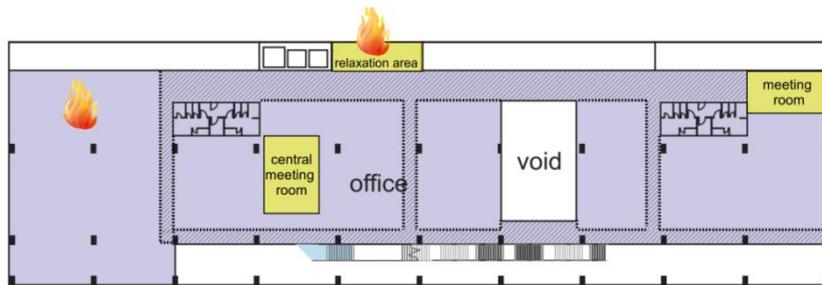


Figure 24: Fire locations on level L7

2.5.3 HRR OF STUDIED FIRES

This section aims at defining the temporal evolution of heat that could be released by the fuels selected in the previous section. In more details, it consists, for each fuel, to define the maximum heat release rate, a growth rate and a heat capacity per unit area. In that frame, the main used scientific references are [26], [17], [23], [19], [15]. Moreover, we make use to French standards for fire safety in high rise buildings [6] and to the recommendations of the French interior ministry.

2.5.3.1 Fire of office furniture

Two fires involve office furniture (desk, storage cabinets and upholstered chairs). One is localized, the other is vaster:

- the localized fire is represented by a tridimensional geometry of 1x1.5x1.75 m³, corresponding to a total burning surface area of 10.25 m² (cf. Ref. [23] et [19]). Height equal to 1.75 m appears to be representative to shutter positioned between two workspaces for privacy. Total mass of burning fuel is around 250 kg, this value is extracted from Ref. [23],

[19] and [15]. Maximum HRR is determined by following the recommendations of the French interior ministry which sets heat released by fire per unit area comprised between 300 and 500 kW/m². Due to the nature of the burning combustible (office furniture), we estimate HRR per unit area at 300 kW/m² i.e. HRR at around 3 MW. This value for HRR is similar to the one in Ref. [23] for workspace fire.

Heat of combustion is considered equal to 20 MJ/kg. This value is a compromise between the values for plastic and for wood [27].

The growing phase is composed of a linear curve during the first 200 s and then of αt^2 curve till around 600 s. This growing phase in two stages allows to represent a slow fire development so that fire ignites at a garbage and spreads to other present fuel like the desk. Also, in 200 s, HRR is reaching linearly 200 kW [26] and then it grows till the maximum value 3 MW with α equal to 0.01172 (medium growth in NFPA 72). The stationary phase lasts 1400 s before HRR decreases by αt^2 curve with α equal to 0.00293 (low decrease in NFPA 72). HRR versus time is plotted on Figure 25.

- the extended fire is represented by a tridimensional geometry of 3x3x1.75 m³, corresponding to a total burning surface area of 30 m² (cf. Ref. [15]). Total mass of burning fuel is around 750 kg. Like localized fire, maximum HRR is determined by following the recommendations of the French interior ministry. We estimate HRR per unit area at 300 kW/m² i.e. HRR at around 9 MW. This value for HRR is similar to the one in Ref. [15] for workspace fire.

Heat of combustion is considered equal to 20 MJ/kg. This value is a compromise between the values for plastic and for wood [27].

As previously, the growing phase is composed of a linear curve during the first 600 s and a αt^2 curve till around 1300 s. More precisely, in 600 s, HRR is reaching linearly 300 kW [26] and then it grows till the maximum value 9 MW with α equal to 0.01172 (medium growth). The stationary phase lasts 1200 s before HRR decreases by αt^2 curve with α equal to 0.00293 (low decrease)

HRR versus time is plotted on Figure 25.

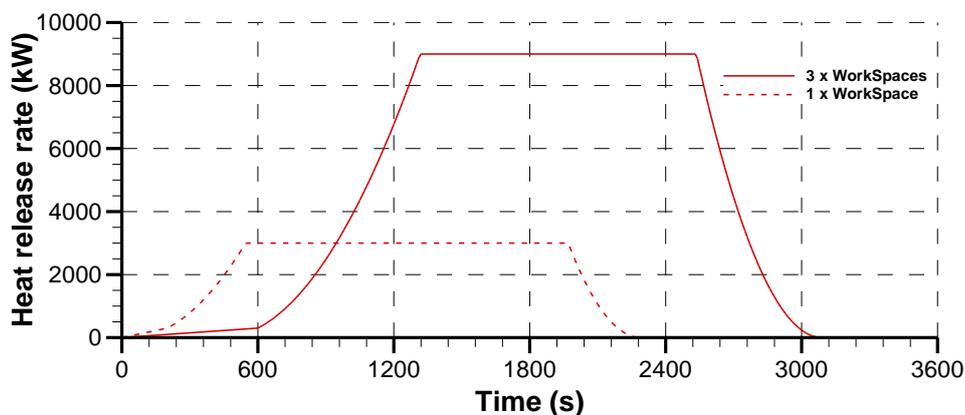


Figure 25: HRR versus time for fires of office furniture (localized and extended)

2.5.3.2 Fire in storage space along floor voids

The fire involves one photocopier machine, one storage cabinet (0.80x0.50x0.80 m³) and reams. Thus, according to Ref. [6], it represents respectively 419 MJ, 703 MJ and 2x41 MJ which roughly corresponds to 1 200 MJ. The fire is represented in simulations by a tridimensional geometry of 1x1x1.50 m³, corresponding to a total burning surface area of 7 m².

Due to the nature of the burning fuel (electric material), the growing phase is a αt^2 curve till around 180 s. HRR is also reaching a maximum value of 1.5 MW with α equal to 0.0469 (fast growth in NFPA 72). The stationary phase lasts 600 s before HRR decreases by αt^2 curve with α equal to 0.01172 (medium decrease). HRR versus time is plotted on Figure 26.

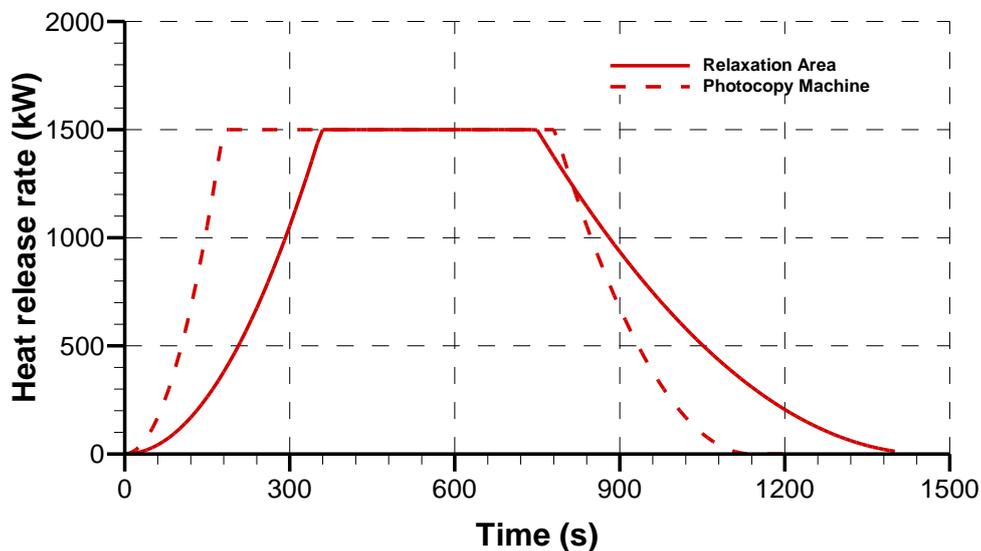


Figure 26: HRR versus time for fire in storage space along floor voids and in relaxation area

2.5.3.3 Fire in relaxation area

Despite our research in the scientific literature, we did not find any information about heat potentially released by fire of coffee machines or drink and snack dispensers. We suppose it is similar to fridges.

Also, the fire involves two fridges, one sofa, one table (120 cm diameter and 22 mm thickness) and four tables. Thus, according to Ref. [6], it represents respectively 2x201 MJ, 201 MJ, 268 MJ and 4x67 MJ which roughly corresponds to 1 200 MJ. The fire is represented in simulations by a tridimensional geometry of 1.00x1.00x1.00 m³, corresponding to a total burning surface area of 5 m².

Due to the nature of the burning combustible (electric material), the growing phase is a αt^2 curve till around 360 s. HRR is also reaching a maximum value of 1.5 MW with α equal to 0.01172 (medium growth). The stationary phase lasts around 400 s before HRR decreases by αt^2 curve with α equal to 0.00293 (low decrease). HRR versus time is plotted on Figure 26.

2.5.4 STUDIED DESIGN FIRE SCENARIOS

Based on the detailed list page 32, we assess the influence of a few parameters in addition to fires

- The place: the opening state of integrated bands dedicated to comfort ventilation at the initial time. When fire is detected, they can be opened or remain closed,
- The safety measures
 - The opening state of each floor void (open, closed): It is investigated to install removable smoke barriers along the edges of floor voids. They go down when the fire is detected to avoid smoke flowing from one level to others via the voids,
 - The presence of permanent 1 m high smoke barriers along each level interconnection,
 - The presence of permanent smoke barriers along the open stairway on the south side. Two heights are simulated, 1 m and 1.5 m,
 - The type of exhaust ventilation system (cf. Section 3.3.3) and the time duration before its activation.

The two following tables list the thirty-five scenarios simulated and used in the present case study. Table 6 concerns the simulations with the different investigated mechanical exhaust ventilation systems (cf. Section 3.3.3). Table 7 concerns the simulations with the natural ventilation system (cf. Section 3.3.3).

Comment: We are aware that the climatic conditions (wind, ambient temperature) can influence notably the efficiency of natural ventilation: wind could prevent smoke from leaving the building or promote smoke dilution. Despite this potential influence, human resources implied in the present study have not been sufficient to conduct such assessment properly. In particular, most of design fire scenarios are modeled with no wind, only one implies a western wind (scenario 35 in Table 7) and in two others, indoor and outdoor temperatures are different (scenarios 33 and 34 in Table 7).

Legend: “DS” means double skin façade, “½ DS on L8” for the bands in the upper part on level L8

Scenario	T _{int} (°C) / T _{ext} (°C)	Studied fire	STATE OF OPENINGS			SMOKE BARRIERS				DETAILS ON VENTILATION		Type of exhaust ventilation system
			Openings at the initial time (m ²)	Openings after a while (m ²)	Time of opening	Removable smoke barriers along the edges of floor voids	Permanent 1 m high smoke barriers along the edges of floor voids	Permanent smoke barriers along the open stairway at south side	Height of smoke barriers along the open stairway at south side (m)	Flow rate	Location of activated vents	
5	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	yes	no	yes	1.5	≈ 12 Vol/h 17 m ³ /s	roof on L4	mechanical
6	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	no	yes	yes	1.5	≈ 12 Vol/h 102 m ³ /s	on south side	mechanical
7	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	no	yes	no	0	≈ 12 Vol/h 102 m ³ /s	on south side	mechanical
8	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	no	yes	yes	1.5	≈ 12 Vol/h 25 m ³ /s	on north side, on L4	mechanical
9	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	yes	no	yes	1.5	≈ 12 Vol/h 105 m ³ /s	on north side, on each level	mechanical
10	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	yes	no	yes	1	≈ 12 Vol/h 105 m ³ /s	on north side, on each level	mechanical
11	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	no	yes	yes	1.5	≈ 12 Vol/h 105 m ³ /s	on north side, on each level	mechanical
15	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	no	no	yes	1.5	≈ 12 Vol/h 102 m ³ /s	roof on each office level	mechanical
16	28/28	II	10.5 (main entry)	51 (DS on L4 + main entry)	225	yes	no	yes	1	≈ 12 Vol/h 102 m ³ /s	roof on each office level	mechanical

Table 6: Design fire scenarios with mechanical ventilation system

Scenario	T _{int} (°C) / T _{ext} (°C)	Studied fire	STATE OF OPENINGS			SMOKE BARRIERS				
			Openings at the initial time (m ²)	Openings after a while (m ²)	Time of opening	Removable smoke barriers along the edges of floor voids	Permanent 1 m high smoke barriers along the edges of floor voids	Permanent smoke barriers along the open stairway at south side	Height of smoke barriers along the open stairway at south side (m)	
1	28/28	II	32 (1/2 DS on L8 + main entry)	32 (1/2 DS on L8 + main entry)	0	no	yes	yes	1.5	
36	15/28	II	32 (1/2 DS on L8 + main entry)	32 (1/2 DS on L8 + main entry)	0	no	yes	yes	1.5	
37	28/15	II	32 (1/2 DS on L8 + main entry)	32 (1/2 DS on L8 + main entry)	0	no	yes	yes	1.5	
2	28/28	II	400 (DS)	400 (DS)	0	no	yes	yes	1.5	
3	28/28	II	32 (1/2 DS on L8 + main entry)	400 (DS)	225	no	yes	yes	1.5	
4	28/28	II	32 (1/2 DS on L8 + main entry)	400 (DS)	225	yes	no	yes	1.5	
12	28/28	II	10.5 (main entry)	400 (DS)	225	no	yes	yes	1	
13	28/28	II	10.5 (main entry)	400 (DS)	225	yes	no	yes	1	
14	28/28	II	10.5 (main entry)	400 (DS)	225	yes	no	no	0	
17	28/28	III	10.5 (main entry)	400 (DS)	with detection (25 s)	no	yes	no	1.5	
18	28/28	IV	10.5 (main entry)	400 (DS)	with detection (25 s)	no	yes	no	1.5	
19	28/28	V	10.5 (main entry)	400 (DS)	with detection (30 s)	no	yes	no	1.5	
20	28/28	VI	10.5 (main entry)	400 (DS)	with detection (25 s)	no	yes	no	1.5	
21	28/28	VII	10.5 (main entry)	400 (DS)	with detection (30 s)	no	yes	no	1.5	
22	28/28	III	10.5 (main entry)	400 (DS)	with detection (25 s)	yes	no	no	0	
23	28/28	IV	10.5 (main entry)	400 (DS)	with detection (25 s)	yes	no	no	0	
24	28/28	V	10.5 (main entry)	400 (DS)	with detection (30 s)	yes	no	no	0	
25	28/28	VI	10.5 (main entry)	400 (DS)	with detection (25 s)	yes	no	no	0	
26	28/28	VII	10.5 (main entry)	400 (DS)	with detection (30 s)	yes	no	no	0	
33	17/28	I	400 (DS)	400 (DS)	0	no	no	no	1.5	
34	28/40	I	400 (DS)	400 (DS)	0	no	no	no	1.5	
RESULTING STRATEGY	27	28/28	II	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	28	28/28	III	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	29	28/28	IV	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	30	28/28	V	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	31	28/28	VI	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	32	28/28	VII	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1
	35 with wind of 10 km/h	28/28	V	10.5 (main entry)	400 (DS)	60 s	no	yes	yes (except on L4)	1

Table 7: Design fire scenarios with natural ventilation system

3. FIRE SAFETY STRATEGY

As mentioned previously, we choose to apply a prescriptive approach based on French building standards for carparks and retail areas on levels L1 to L3. Also, the performance-based fire safety study is conducted at the office level scale and not at the building scale. This choice is motivated by the insufficient human resources implied in the present study.

3.1 FIRE SAFETY STRATEGY FOR CARPARK

In the case study, it is not specified if carparks are only accessible by the members from the corporate headquarters office. We can also suppose that retail customers can have access to it too. Consequently, carparks are not regulated by the labor code but rather by the French building standards for public buildings which is more rigorous and more binding. Thus, we apply the prescriptions for public buildings.

Carparks extend over three levels. The intermediate park on the level L2 is at the reference level¹. Surface area of every level is the same, it is equal to 3000 m². Regulation proposes two options, either mechanical smoke exhaust systems or natural. We opt in the present case study for a widely ventilated carpark. It induces that the north, south and west façades have openings representing at least 50 % of their total surface. This large ventilation allows to ensure natural smoke exhaust in case of fire. The level L1 being partly underground, it is connected by its ceiling by six openings of 100 m².

Other prescriptions are respected:

- The distance for people to reach a stairway or outside does not exceed 40 m if the person is between two opposite stairways, and 25 m if the user is in a dead end,
- Stairways can be open or enclosed, their width measures at least 0.9 m.

Fire resistance regulations require a structural fire stability of 1h30, and firebreak intermediate floors with a structural fire stability of 1h30.

3.2 FIRE SAFETY STRATEGY FOR RETAILS

The smoke exhaust system in the retail is designed following the French building standards. For retails with surface area smaller than 1000 m², vents of a natural system must represent 1/200 of the retail surface area.

In the present case study, the retail measures 630 m². Considering a ventilation coefficient of 0.5, we obtain that vent surface area is equal to 6.3 m². This surface is distributed on three vents placed in the upper part on the north, west and south façades of the retail. The fresh air is supplied by the retail access doors, two on the north side and two on the south side, every exit is 1.4 m wide. Moreover, a water-based fixed firefighting system is installed to limit fire spread and quickly attack

¹ The level of the public road which serves the building is usable by the public services machines and by firetrucks

the fire. Communication with the carparks is established through an airlock system equipped with fire doors opening inward and provided with a farm-door.

No fire resistance verification of the structure is required since fixed firefighting system is installed.

3.3 INVESTIGATED STRATEGIES FOR THE OFFICE LEVELS

Three fire safety strategies have been investigated, each one being characterized by specific structural, organizational and technical aspects.

3.3.1 STRATEGY A: AUTOMATIZED AND FAST ACTION ON FIRE

Strategy A aims at limiting fire spread and its heat release rate. It relies on water-based fixed firefighting systems (sprinkler system, water mist system) and/or gas-based fire suppressing systems. The first category of systems can be installed in workspaces, meeting rooms, etc. The second category of systems must be prioritized for specific closed spaces (for instance the IT unit office, the network server room and the archives in the case study) with the additional advantage to limit the collateral damages due to the use of water. Strategy A requires detecting the fire for activating the firefighting systems.

The water-based or gas fixed firefighting systems could be completed by ventilation systems. Indeed, fixed firefighting systems may penalize the smoke stratification. In that context, ventilation systems could minimize the time after fire extinction to get the building back in service as early as possible. Moreover, it could extract smoke during fire and also perhaps ensure safe conditions for occupants too.

In the present case study, the assessment of this strategy A is based on scenarios involving fire on short duration. In practice, we focus our study on heat or smoke detectors (response time, detector spatial distribution, etc.). The main goal with this strategy is to ensure conditions allowing to people to safely and quickly leave the building or let them to reach a safe place

3.3.2 STRATEGY B: FAST HUMAN ACTION ON FIRE

Strategy B aims at limiting fire spread and its heat release rate. It relies on human action. The safety measures allow to detect the fire, to locate the fire and to react quickly. It relies on equipment and the personnel at the safety guard post, heat/smoke detectors and alarm system in the building, with or without duration for doubt removal by the building personnel, personnel training and personnel awareness of the fire strategy. A fixed firefighting system could be installed in specific hazard spaces in addition (for instance the IT unit office, the network server room and the archives in the case study).

In the present case study, the assessment of this strategy B is based on the scenarios involving fire on longer duration. This duration corresponds to the time needed for detection, fire localization, for dispelling any doubt and fire control by the trained personnel.

3.3.3 STRATEGY C: FAST BUILDING EVACUATION AND FIRE FIGHTERS OPERATION

Strategy C aims at favoring people to safely and quickly leave the building or let them to reach a safe place. This strategy relies on safety measures to extract sufficient smoke in order to conserve safe conditions for evacuation. It relies on additional measures to minimize the time necessary for egress and for going in safe place.

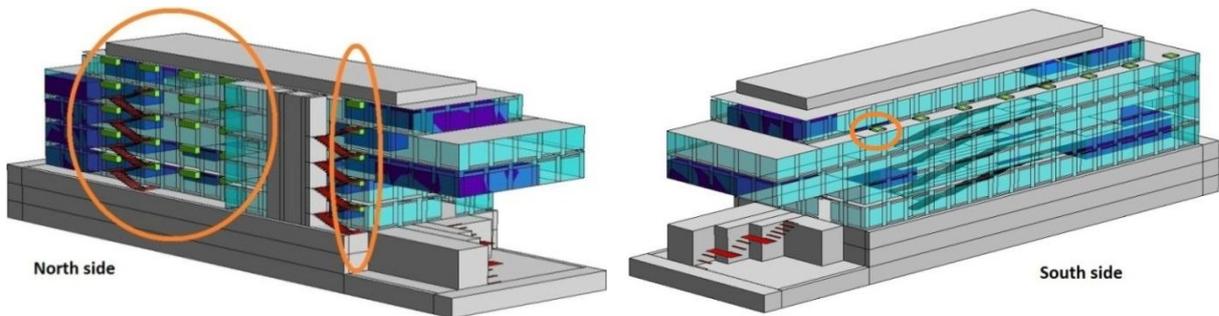
The safety measures for extracting smoke consist mainly in smoke exhaust system:

- For mechanical systems, the vents can be positioned on façades or close to the roof on each level.

- On façades, two possibilities appear interesting. Vents are positioned either on the north or south side.

On the north side, vents are positioned on each level, in the upper part, close to the roof. Their location is showed on Figure 27. If the induced depression is sufficient, it would captivate the smoke produced by a fire on the concerned level and also allow to let a free smoke area on other levels and in the open stairway on the south side. The investigated exhaust flow rate is around $100 \text{ m}^3/\text{s}$ when all levels are activated, it is equal to $25 \text{ m}^3/\text{s}$ for only one level.

On the south side, we imagine that consecutive depression will captivate the smoke on south and that the smoke would flow through the open stairway by letting other levels free of smoke. Fresh air is supplied at the opposite side to the exhaust vents. This solution is illustrated on Figure 27. The investigated exhaust flow rate is around $100 \text{ m}^3/\text{s}$, it represents roughly 12 times the volume on each level.



a- With vents positioned on north façade

b- With vents positioned on south façade

Figure 27: Two investigated mechanical exhaust systems

- Close to the roof, vents are distributed uniformly on each level. In that case, the investigated exhaust flow rate is around $100 \text{ m}^3/\text{s}$ when all levels are activated, it is equal to $17 \text{ m}^3/\text{s}$ for only one level.

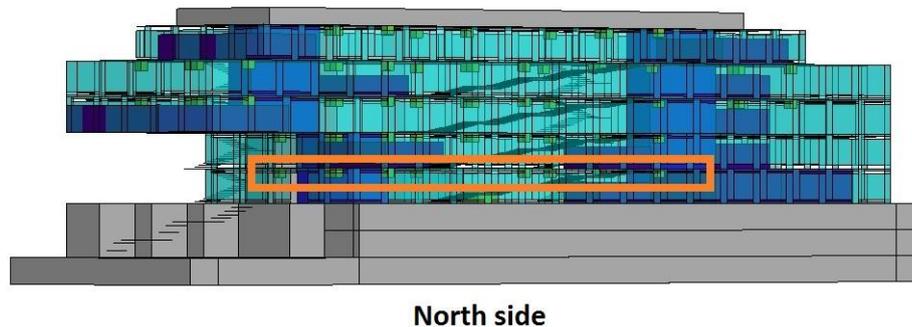


Figure 28: Mechanical exhaust system with vents positioned close to the roof

- For natural system, the idea is to make use of integrated bands dedicated to comfort ventilation. These bands represent roughly 10 % of the total façade area i.e. 400 m². By referring to the French building standards, a natural system in the building would be constituted of vents of 30 m² per level for air supply and the same for smoke exhaust. Integrated bands represent 80 m² per level, 40 m² for air supply and 40 m² for smoke exhaust.

In addition to smoke exhaust systems, smoke barriers can be positioned in the building to optimize the influence of ventilation systems to isolate the fire concerned level and to create a smoke reservoir. These barriers can be imagined permanent in the building and thus built at the origin of the building. Otherwise, they can be imagined temporary (removable smoke barriers which goes down in case of fire, water curtain...). In that case, height of barriers can be equal to office level height. The smoke barriers are imagined to be positioned along the open stairway on the south side and/or at floor voids location.

With the aim to minimize the time necessary for egress and for going in safe place, a few possibilities exists:

- Define areas, exit of smoke, flame and thermal radiation that people can reach in case of fire and wait for their evacuation with the arrival of an external assistance (fire brigades for instance).
By considering the building at this stage, the meeting rooms are sufficiently dispersed to constitute easily such areas. However, the difficulty lies on their modest sizes relative to the building occupancy. Indeed, the two 50 m² meeting rooms on level L5 would shelter 140 persons, the 50 m² meeting room and the 300 m² auditorium on level L6 would shelter 290 persons, the two 50 m² meeting rooms on level L7 would shelter 170 persons. However, more meeting rooms would question the building design and its performance in energy. Moreover, it is conceivable that in case of fire, people prefer evacuating via the single stairways than staying in such areas and waiting an external assistance. Thus, it appears difficult or even impossible to let the fire safety strategy relies only on this possibility.

- Build additional stairways serving each level to facilitate people evacuation. The already existing stairway being on the south side, stairways are regarded on the north side at distant positions. To guarantee safe conditions to people at any time, they are enclosed or out of the building, protruding from the carcass. The longest pathway for people is consequently reduced.
- Make a more extensive use of the elevator located at north.

Last, a fixed firefighting system could be installed in specific hazard spaces in addition (for instance the IT unit office, the network server room and the archives in the case study).

In the present case study, the assessment of this strategy C is based on the scenarios involving fire on the longest duration corresponding to the time for fire fighters to arrive on site and to operate.

3.4 RESULTING STRATEGY FOR THE OFFICE LEVELS

The strategy presented below results from the best compromise for us between fire safety, its financial impact and its technical feasibility:

This strategy involves **two additional stairways on the north side** at two distant positions. Each serves each level from L4 to L8 by one 2.4 m wide door. All the building is evacuated at the same time. People on L5 to L8 evacuate the building via the main entry on level L4 by going down by the stairways. These additional stairways facilitate people evacuation by offering other ways to evacuate than open stairways on the south side. People have also one stairway within a radius of 25 m (cf. Figure 29). Moreover, since they are enclosed, they guarantee at least two safe ways to people at any time.

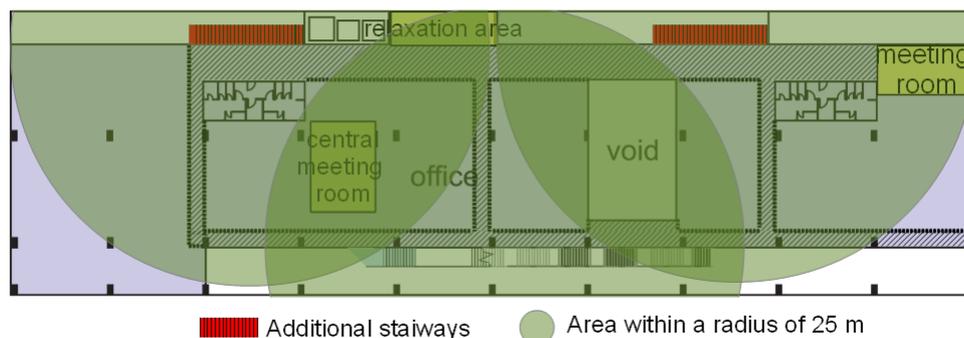


Figure 29: Areas centered on stairway and within a radius of 25 m (example of level L7)

On level L8, a terrace surrounds the building. In order to minimize the time necessary for egress and for going in safe place, **four doors (two on the east side and two on the west side)** allow to people to reach the terraces from workspaces and aisles (cf. Figure 30). From these terraces, there is a direct access to the enclosed stairways on the north side with gates. For security in the every-day conditions, these gates can be opened only from the terrace to the stairway.

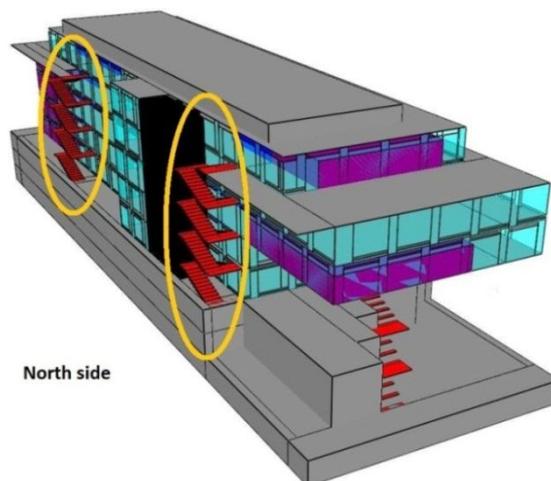


Figure 30: Two additional stairways on the north side

On each office level, walls of the **two enclosed stairways** are resistant to fire, they are isolated to the rest of building. They **constitute areas, exit of smoke, flame and thermal radiation** that people can reach in case of fire and wait for their evacuation with the arrival of an external assistance (fire brigades for instance). These areas are **destined primarily for people with disabilities**.

The resulting strategy involves a **fixed firefighting system in specific hazard spaces** (the IT unit office, the network server room and the archives in the case study). **Natural ventilation on office levels** for supplying fresh air and evacuating smoke by taking advantage of the openings through the double skin façades designed for comfort. It also consists in considering a dual role for the façade in the operation of the building, for comfort in the every-day conditions and for fire safety in exceptional conditions.

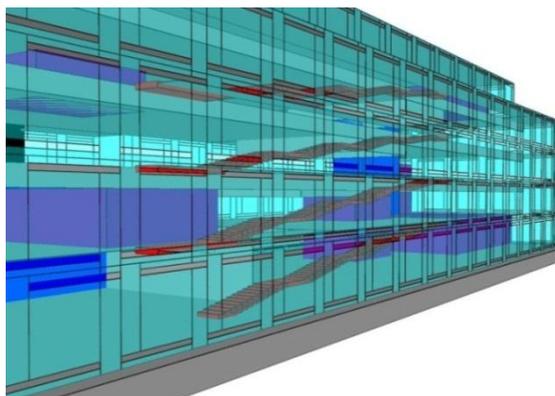


Figure 31: Bands integrated in the double skin façades on the north side

Also, all natural ventilation is ensured by the **25 cm high integrated bands representing 400 m² in total and positioned on the four sides of the building** (150 m² on north/south side and 50 m² on east/west side). Their distribution is represented on Figure 31. Simulations have showed that this natural ventilation is as good as or better than all investigated mechanical ventilations. Moreover, this ventilation is preferred since it is already set up for ensuring comfort.

The resulting strategy is based on automatization of the openings of natural ventilation vents with smoke detectors. In order to react as early as possible, **all bands in the double skin façade are opened when smoke is detected except when it is windy, bands located on the façade incident to wind should remain closed.** Limit amplitude of wind would need to be evaluated. In that frame, **detectors are installed uniformly on all office levels, on ceiling (cf. Figure 33) so that to get 1 detector per 60 m²** (cf. Figure 32). This distribution follows the recommendations of the European norm NBN S21-100.

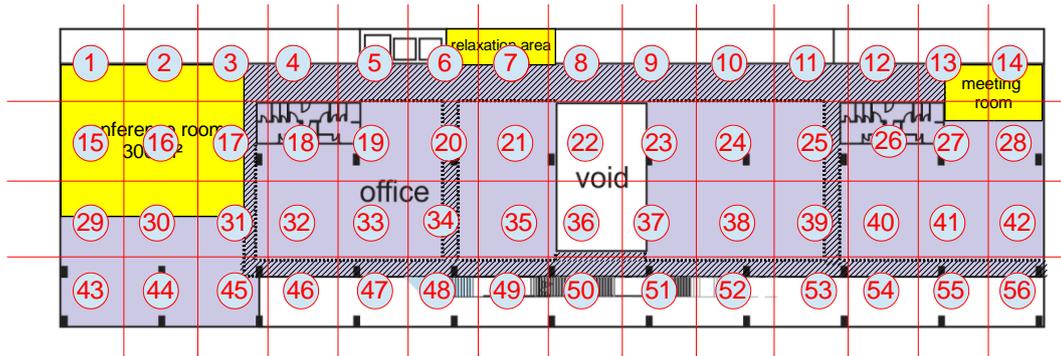


Figure 32: Distribution of smoke detectors on level L6

With this distribution, we have estimated numerically the maximum delay for the studied scenarios around 60 seconds. When fire is detected by heat/smoke detector or manual call points, the Fire Indicator Panel operates the façade bands remotely. In practice, time duration can be defined between detection and openings to let personnel dispel the doubts. The large building dimensions and the interconnection between levels by floor voids contribute to smoke dilution. Thus, this dilution let us to consider this duration set to zero to reach the goal to open the façade bands as early as possible. In other words, **bands are opened as soon as smoke is detected.**

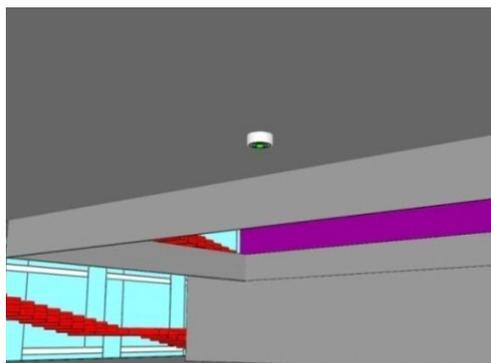


Figure 33: Smoke detectors positioned at a ceiling

In addition to smoke detectors, **glass break detectors are positioned on all office levels, one at proximity of each stairway on north and south side.**

People are invited to evacuate with a voice alarm system constituting of an alarm tone followed by a female voice to attract attention and a male voice to deliver instructions [17]. This type of alarm

appears appropriate for the present building. It is preferred to prevent occupants believe that the alarm is false, they need to understand the seriousness of the situation. This measure would lessen the time duration for evacuating.

The resulting strategy involves **permanent smoke barriers**. They are **1.5 m high and positioned at the edges of each floor void** (cf. Figure 34). They allow to optimize the influence of ventilation systems by creating a smoke reservoir and by limiting the smoke propagation to other office levels. Compared to the temporary barriers which go down till the floor in case of fire, the also designed permanent smoke barriers are as efficient except when the fire is located just under the floor voids.

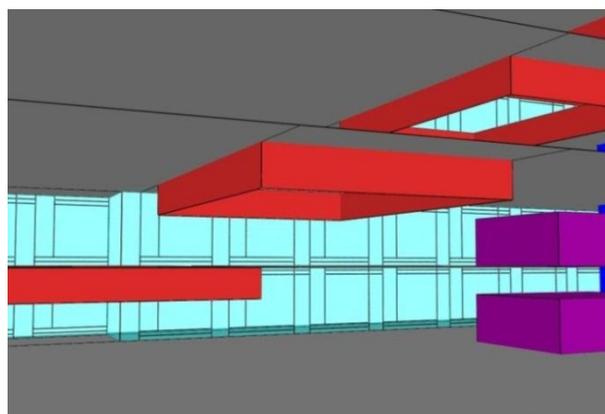


Figure 34: Permanent smoke barriers positioned at the edges of the floor voids, colored in red on Figure

Permanent smoke barriers are positioned along the open stairway on the south side too, on office levels from L5 to L8 (cf. Figure 35). Like other barriers, these barriers allow to optimize the influence of ventilation systems by creating a smoke reservoir. **These barriers are 1.0 m high.**

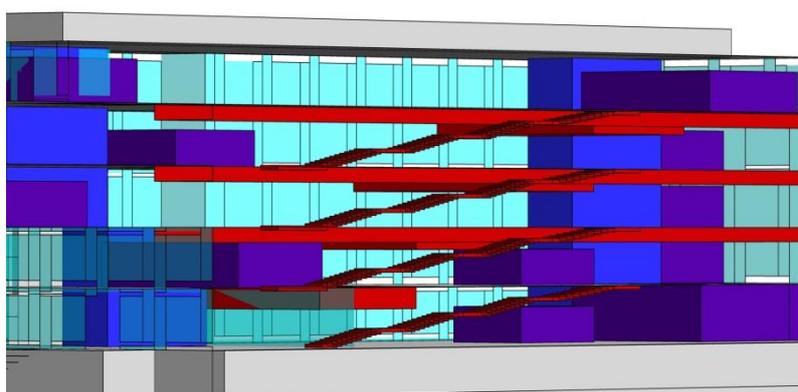


Figure 35: Permanent smoke barriers positioned along the open stairway in red

Thus, these permanent smoke barriers are smaller than other barriers positioned at the edges of the floor voids in order to promote smoke flow toward open stairways rather than toward floor voids. There is no barrier along the stairway on level L4 since it is necessary to get there a maximum height free of smoke. Indeed, stairways serve from each office level the level L4 for people evacuation.

Personnel is informed and formed to their role. They need to have a dedicated education and a perfect knowledge about the building, its material, they must be familiar with the procedures. In case of fire, they help people to evacuate, they verify the integrated bands are opened, they open them if not, they call the fireguards and attempt to extinguish fire when it is feasible with their equipment.

3.5 JUSTIFICATION OF THE RESULTING STRATEGY FOR THE OFFICE LEVELS

The three strategies have been investigated based on the thirty-five design fire scenarios presented in section 2.4.2. Most of them imply fire II which involves office furniture (desk, storage cabinets and upholstered chairs) on a surface area of about thirty m². This fire is located on level L4, close to open stairway and to floor voids between L4 and L5. This fire is considered as the most critical since smoke will likely flow within the building to every level. It also constitutes the most challenging fires for strategies to let all levels free of smoke.

In the following section, we made the choice to not represent all the numerical results but only the ones that figure out and illustrate our conclusions.

3.5.1 FIRE DETECTION AND DELAY OF REACTION

Figure 36 and Figure 37 present instantaneous results on vertical plane along the longitudinal aisle on the south side (cf. Figure 15 to see the plane location within the building). These results have been obtained without any smoke exhaust system. These figures demonstrate that even with a fire releasing a high rate of heat, smoke is rapidly diluted and smoke temperature is consecutively low. Indeed, whereas extinction coefficient is higher than 0.5/m on level L5 after 300 s, gas temperature remains below 60 °C till 900 s even on level L4 where fuel is burning. As expected, the smoke dilution is due to the large building dimensions and the strong interconnection between levels. Based on this low gas temperature, it is not conceivable to consider gas temperature as a quantity to detect smoke. In other words, all systems based on temperature such as thermal camera, heat detector and glass bulb for sprinkler system cannot be used in such configuration, especially as fire would be likely hidden in reality due to office activity. It is also necessary to detect smoke with other technology like beam detector and as close as possible to the fire location.

Smoke detectors are distributed uniformly on each office level, close to the ceiling. Roughly one detector is installed per 60 m² (cf. Figure 32). To estimate the time duration necessary to detect a fire with such distribution, FDS code has been used for simulating photoelectric detectors based on a light transmitter. Its characteristics being unknown, inputs are the one suggested by NIST for "Cleary Photoelectric P2" [20]. With this distribution, in case of fire II, smoke is detected between 30 and 67 s following the openings state of integrated bands in the double skin façade during the simulation. The second and the third detectors are activated later, the second detector roughly 15 s after the first detector and the third detector roughly 30 s after the second detector. It means that after a few minutes with this distribution, at least three detectors are activated rapidly. The delay of activation is strongly influenced by the temperature difference between indoor and outdoor. Indeed, when fire

ignites, HRR is low, smoke temperature is low and its movement is controlled by the natural airflow within the building.

Scenario	Openings state	T _{int} (°C) / T _{ext} (°C)	Activation time		
			first detector	second detector	third detector
1	DP closed	28 / 28	29.8 s	42.2 s	61.4 s
36	DP opened	15/28	43.9 s	56 s	68.6 s
37	DP opened	28/15	67.4 s	83.7 s	97.4 s

Table 1: Activation time of detectors, without smoke exhaust system

Figure 36 and Figure 37 illustrate that smoke is flowing through the floor voids to fill the upper part of the level above. The fact to fill the level above as rapidly is explained by the fire location. In that case, fuel is positioned below the void. Results show that at almost the same time, smoke fills the rest of the building, from level L6 up to level L8. This time corresponds to the time when smoke layer becomes higher than the height of the smoke barrier positioned at the edges of the floor voids between levels L5 and L6. In other words, when smoke begins to flow from one level to another through a void, there is smoke in all upper office levels in a short while without any ventilation system. Consequently, performance of each strategy A, B and C relies on the delay to react. The delay to react being conditioned by the time needed to detect the fire, it appears necessary to set the delay to react from detection to zero. In practice, this time duration allows to let personnel dispel the doubts when a detector is activated.

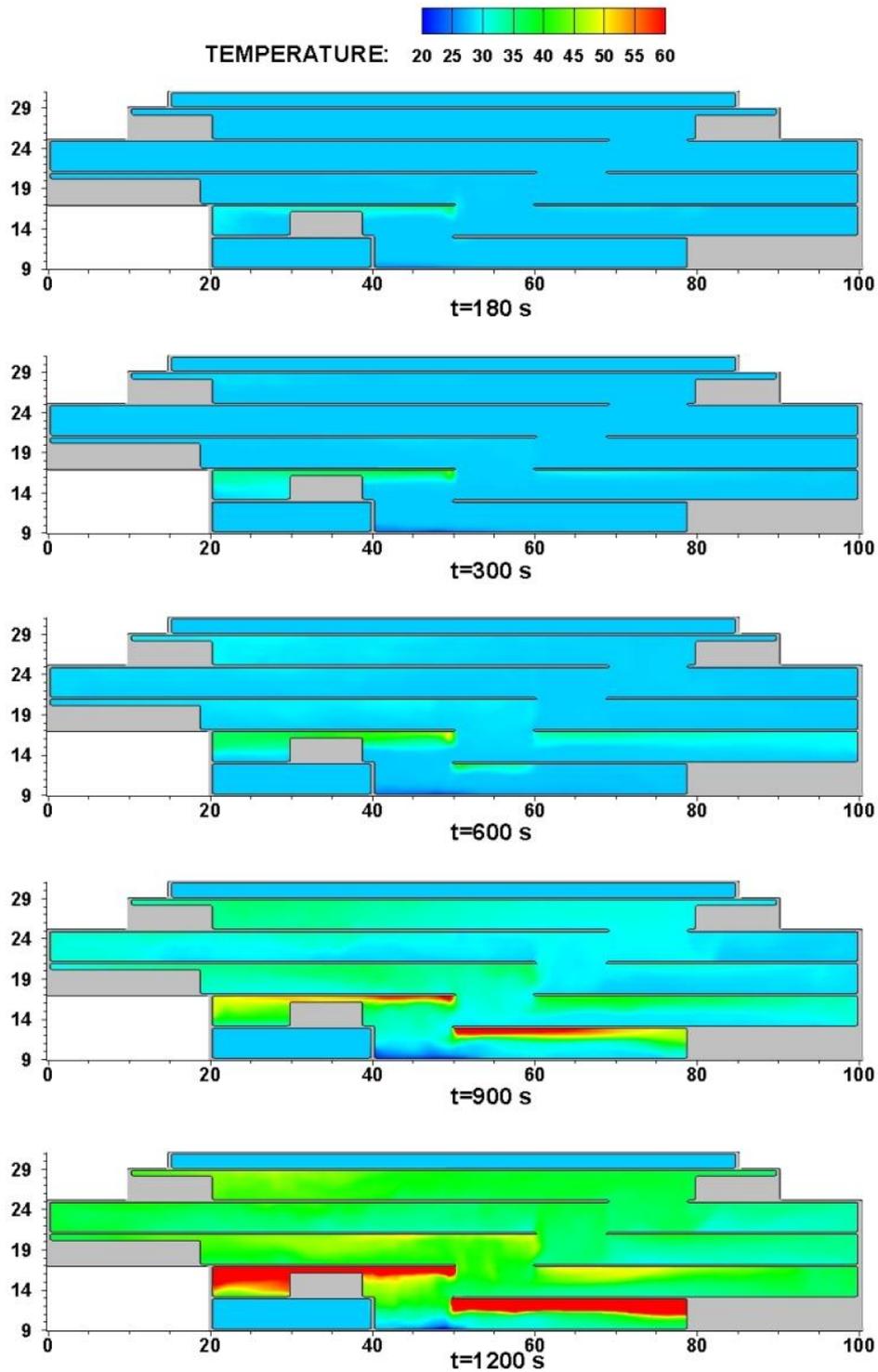


Figure 36: Temperature contour at given times at y=10 m, without smoke exhaust system (scenario 1)

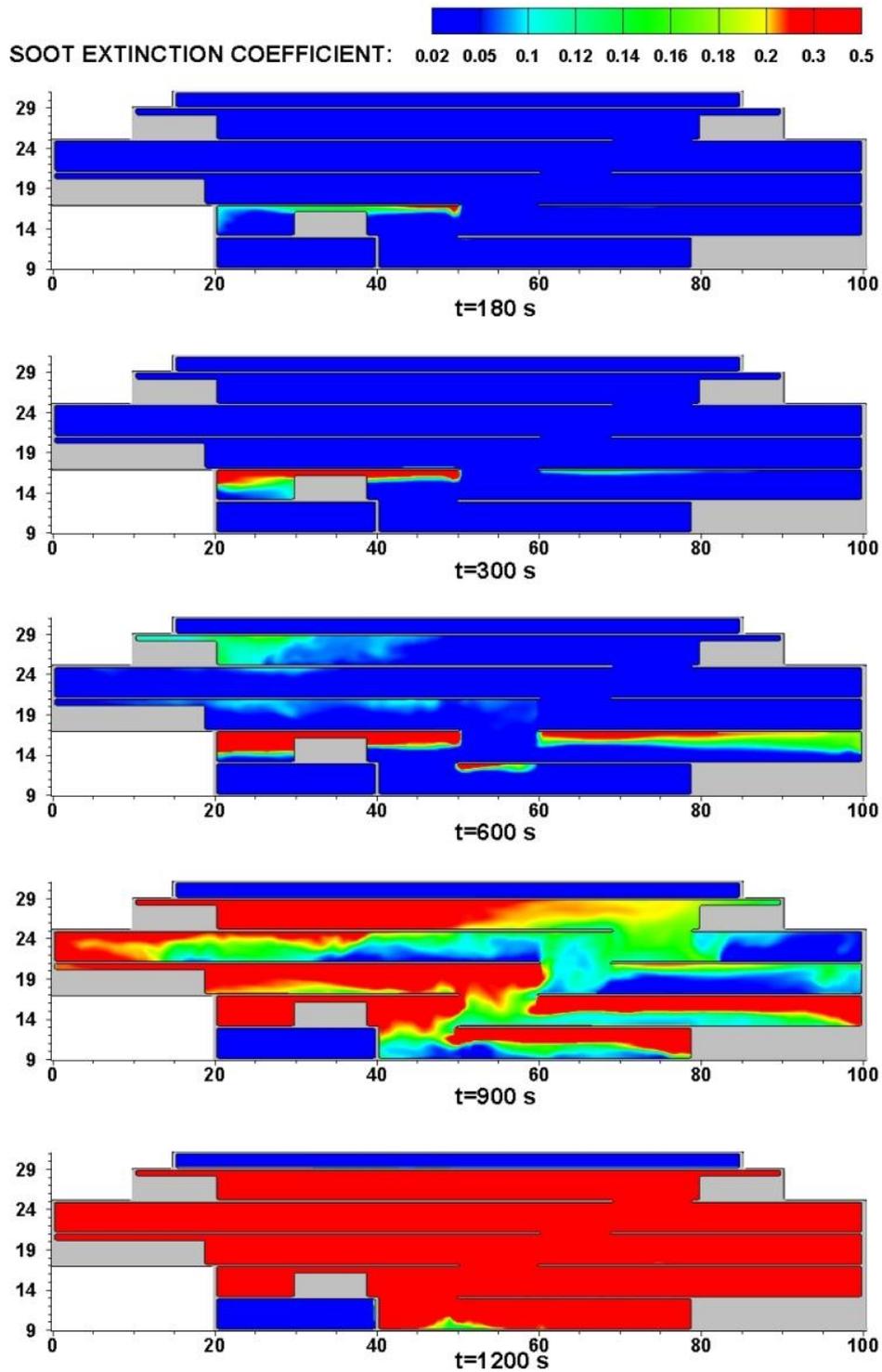


Figure 37: Extinction coefficient contour at given times at y=10 m, without smoke exhaust system (scenario 1)

3.5.2 FIREFIGHTING SYSTEM

The delay between smoke detection and activation of the safety measure is set to zero. If strategy A is selected, we can also predict collateral damages in case of unnecessary activation of a firefighting system. Moreover, in France, the strategy in case of fire is deeply based on ventilation system rather than firefighting system. This strategy aims at maintaining a free-smoke area near the floor as long as possible in order to promote self-evacuation of people and improve the operating conditions for fire-fighters. Consequently, we look to propose an alternative to a 100% sprinkler protection of the building with a smoke exhaust system, corresponding to strategy B or C.

3.5.3 SMOKE EXHAUST SYSTEM

Figure 38 presents instantaneous results on vertical plane along the longitudinal aisle on the south side. These results have been obtained with a mechanical smoke exhaust system on the south side. This fire is particularly unfavorable for this smoke exhaust system since it is in the lowest level. However, the tested exhaust flow rate is huge, it represents twelve times the building volume per hour i.e. roughly $100 \text{ m}^3/\text{s}$. In comparison with Figure 37, Figure 38 illustrates that, despite this flow rate, conditions within the building appear to be similar to the one without smoke exhaust system during the overall scenario time duration. This result can be explained by the large building dimensions and the strong interconnection between levels. The depression generated by the smoke exhaust system is not sufficient to captivate the smoke on the south side in the open stairway and let levels free of smoke.

Based on this result, the idea has been to position the vents closer to the fire location. In the second investigated smoke exhaust system, vents are located on each office level on the north side. The exhaust volume flow rate represents twelve times the level volume per hour i.e. $25 \text{ m}^3/\text{s}$. In a first time, smoke is exhausted only via the vents on the level concerned by the fire i.e. L4 in that case. Figure 39 presents results on vertical plane along the longitudinal aisle on the south side. This figure shows that this system conducts to the same conditions till 900 s. Then, when smoke is present at each office level, it allows to get better conditions in the lower level part until each office level is totally filled of smoke at 1200 s. In other words, this exhaust system allows only to get a delay before smoke fills the overall building.

Thus, we tested the same smoke exhaust system but vents are activated on all levels. In case of fire II, all vents are also activated and the consecutive exhaust flow rate is four times higher. Figure 40 presents the obtained results. In comparison with Figure 39, Figure 40 shows that despite exhaust flow rate is higher, the also get conditions within the building are similar. Depression induced by the smoke exhaust system does not captivate the smoke enough on the concerned level.

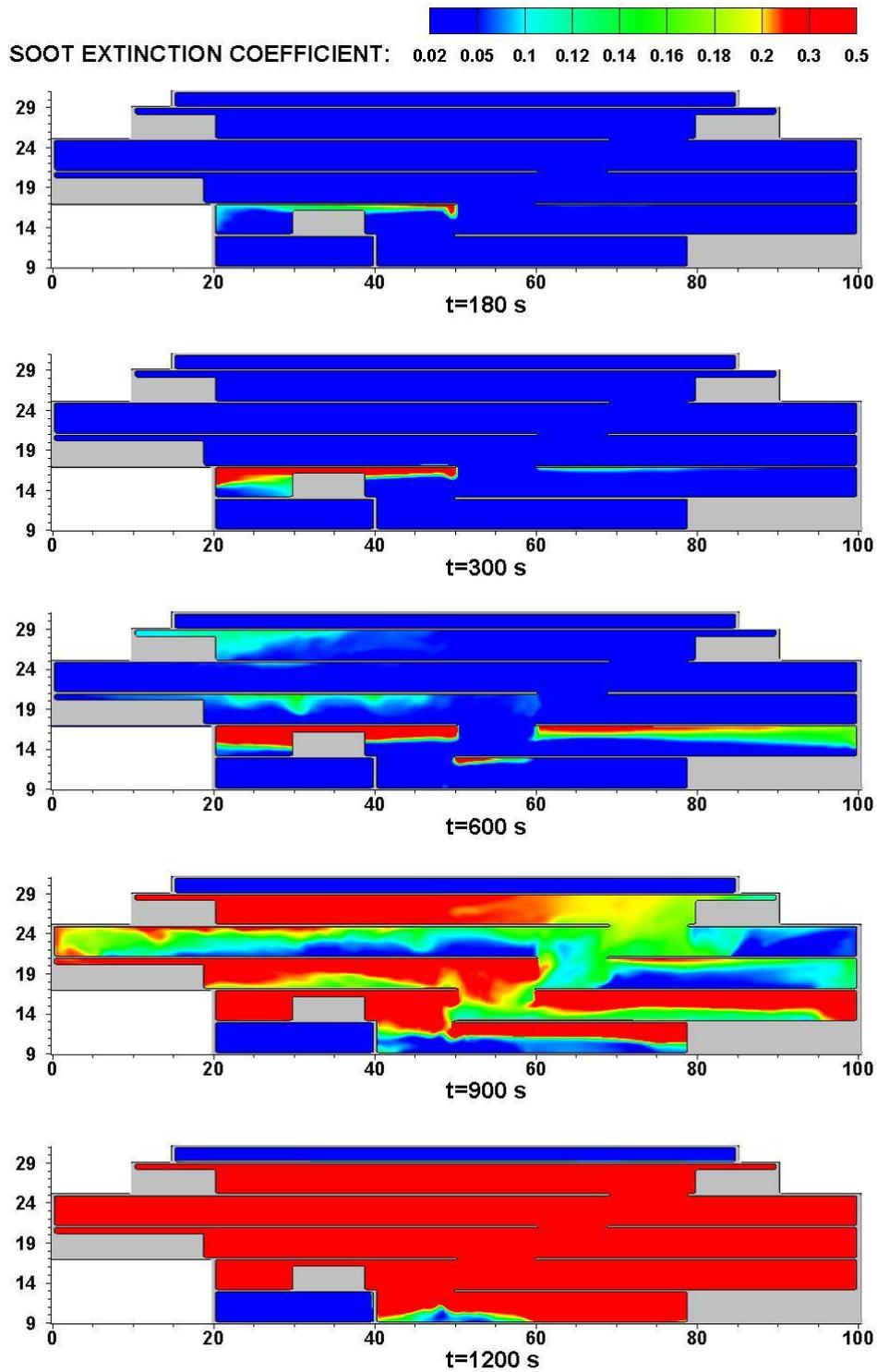


Figure 38: Extinction coefficient contour at given times at y=10 m, with the mechanical smoke exhaust system on the south side (scenario 6)

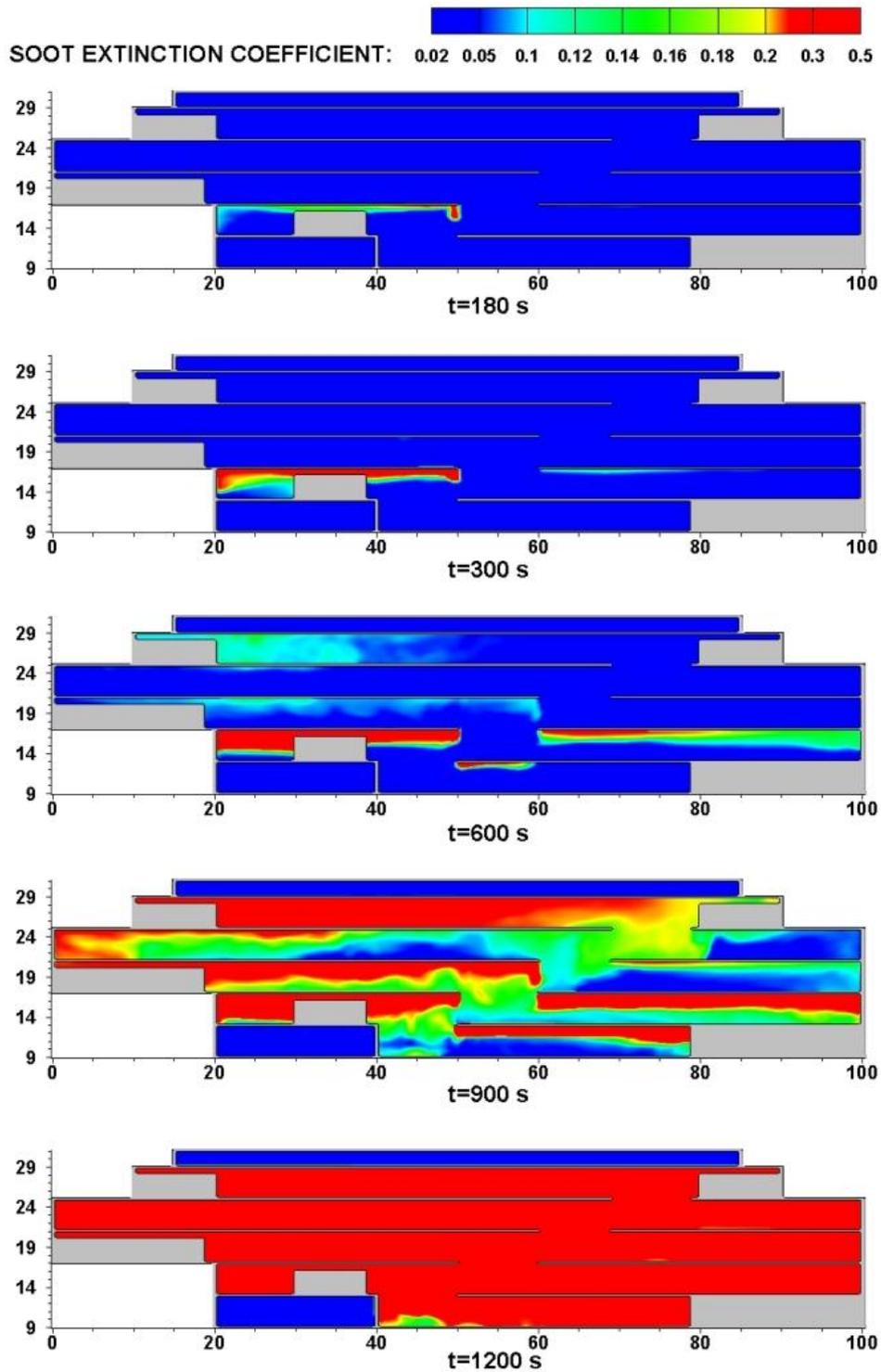


Figure 39: Extinction coefficient contour at given times at y=10 m, with the mechanical smoke exhaust system on the north side on L4 (scenario 8)

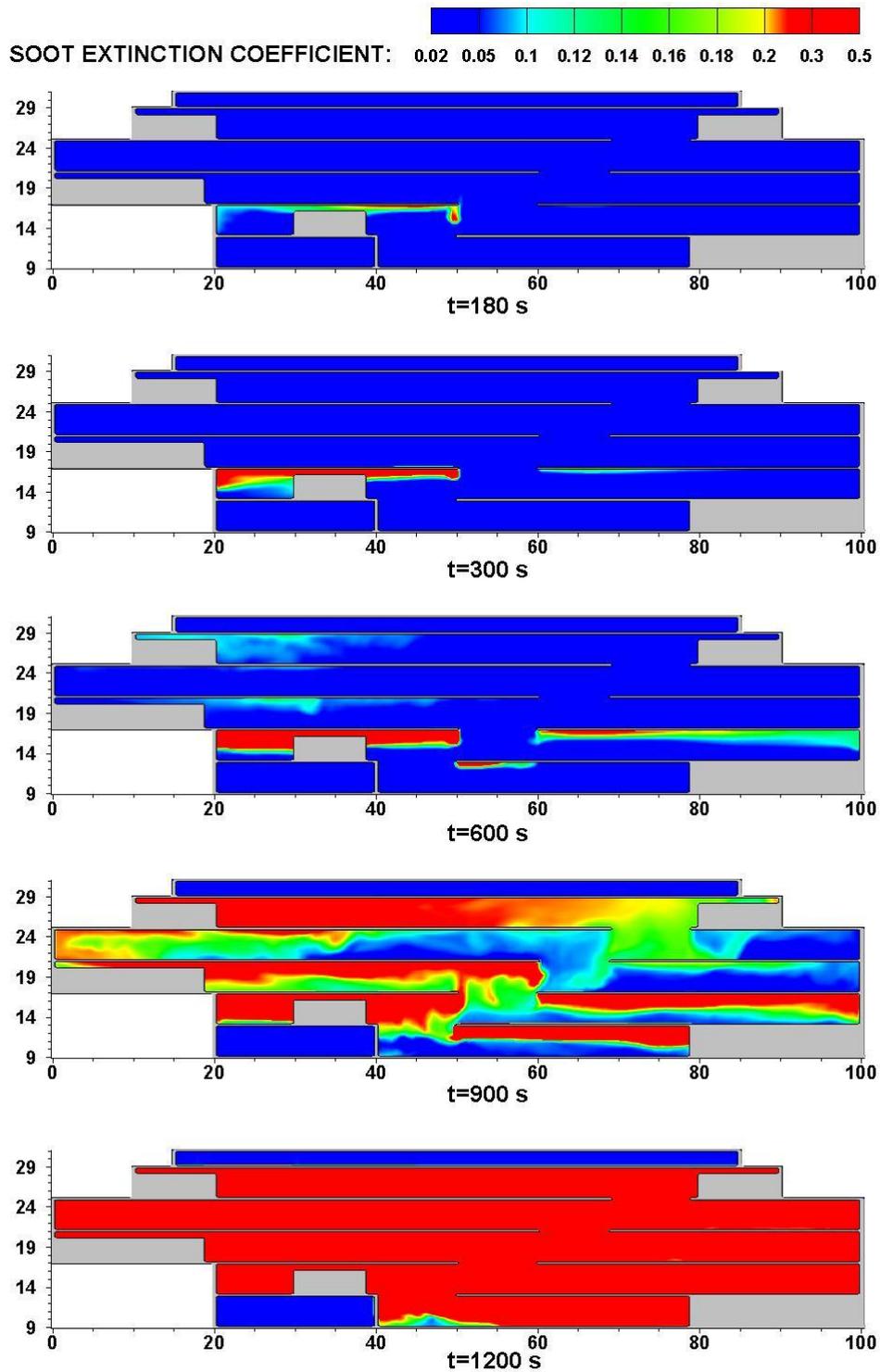


Figure 40: Extinction coefficient contour at given times at y=10 m, with the mechanical smoke exhaust system on the north side on each level (scenario 11)

The last tested mechanical system involves vents distributed on each level close to the roof. They are also closer to the burning fuel. Figure 41 presents the obtained results on vertical plane along the longitudinal aisle on the south side. In comparison with previous results, this figure clearly demonstrates the large impact of this system on conditions within the building. Indeed, before 600 s, smoke is compartmented in the floor void between L4 and L5 closed with temporary smoke barrier. After 900 s, smoke is present in the upper part on level L4 by constituting a 1 m high smoke layer, it is present on each other level, at the location of interconnections and with a very thin layer in its upper part. After 1200 s, when office levels are totally filled with smoke with other tested smoke exhaust systems, this system allows to improve conditions in the lower part on level L4. However, such conditions remain not sufficient for evacuation.

A natural system is assessed. Bands integrated in the façade for ensuring thermal comfort represent a surface area which is used to exhaust smoke and supply fresh air. Figure 42 presents the obtained results on vertical plane along the longitudinal aisle on the south side. In comparison with Figure 41, these results are almost identical during the scenario time duration. More precisely, building smoke-filling described in the paragraph above is similar: smoke is first compartmented in the floor void closed with temporary smoke barrier, then it is present in the location of interconnections and with a thin layer on L4, last smoke fills the building except in the lower part on L4. Finally, the natural system based on bands leads to the same level of performance as the previous mechanical system. It is even slightly better since smoke flow seems to be less perturbed and after 1200 s, the layer of fresh air on level L4 appears thicker.

In conclusion, two smoke exhaust systems lead to almost the same level of performance, one is mechanical, the other is natural. The first system requires a fan and ductwork corresponding to installation and maintenance costs. Moreover, place ducts close to the roof will obstruct the space between suspended ceilings and ceilings. It goes against our bias for conception where we aim at promoting a maximum use of natural aeraulic flow. The second system is already installed since it is required for ensuring thermal comfort. Based on the numerical results, owing to its augured simplicity of implementation and its corresponding cost, the natural system is preferred.

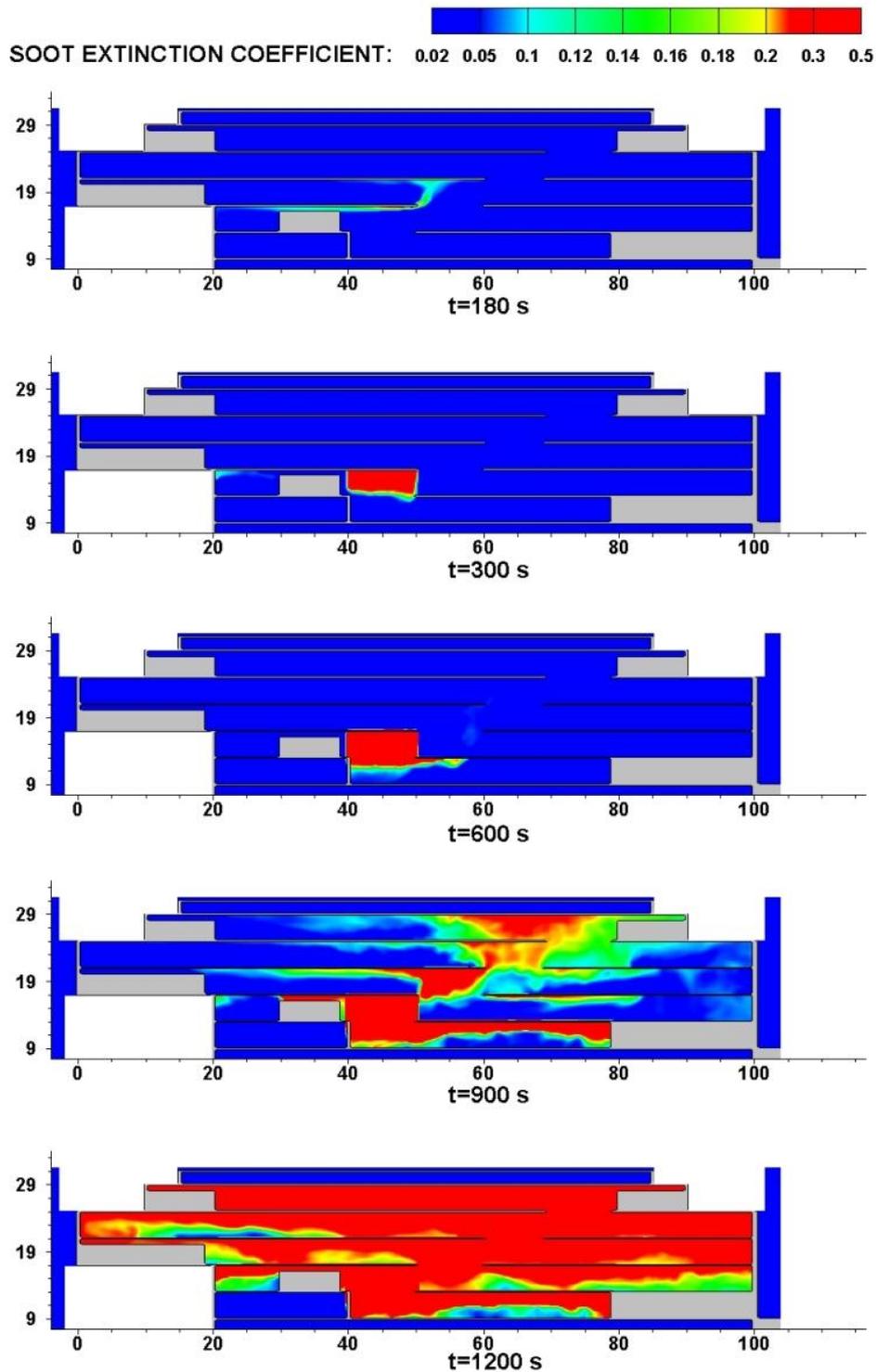


Figure 41: Extinction coefficient contour at given times at y=10 m, with the mechanical smoke exhaust system close to the roof (scenario 16)

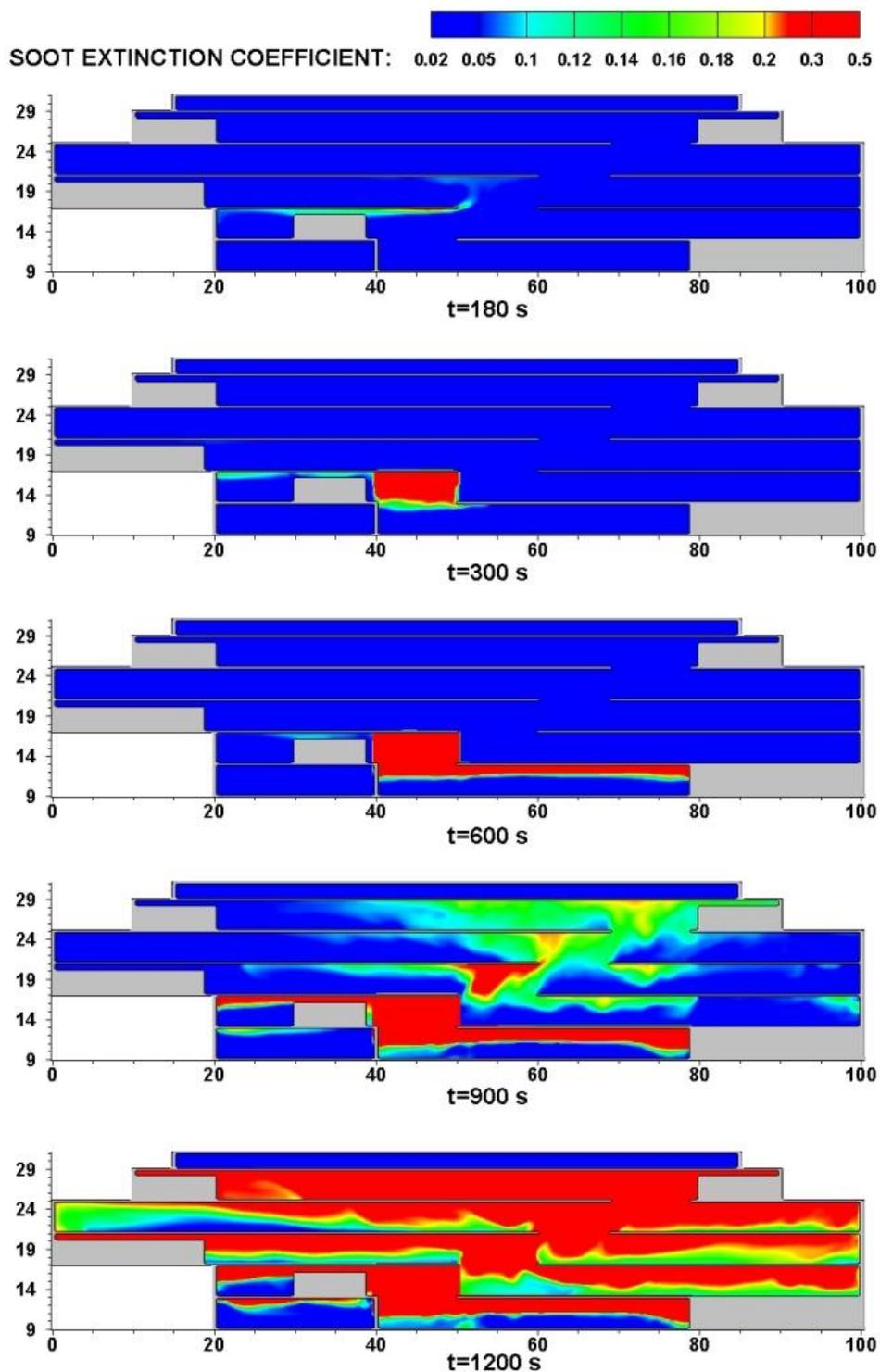


Figure 42: Extinction coefficient contour at given times at $y=10$ m, with the natural smoke exhaust system and temporary smoke barriers along the edges of floor voids (scenario 13)

3.5.4 SMOKE BARRIERS

Smoke barriers could be at two positions, at the edges of the floor voids and along the open stairway on the south side. Such barriers aim at limiting smoke spread within the building. Two types of barriers are assessed for the floor voids, either permanent or temporary. Temporary barriers are removable and go down in case of fire. Their height is equal to office level height. Otherwise, permanent barriers are a few meters high not to perturb air flow in normal conditions and to keep a visual harmony.

In the building configuration, in case of fire II, such barrier has already demonstrated their utility. Indeed, in scenario 1 without any smoke exhaust system, Figure 36 and Figure 37 illustrate that when smoke layer becomes higher than the height of the smoke barrier positioned at the edges of the floor voids between levels L5 and L6, smoke fills the rest of the building, from level L6 up to level L8, in a short while.

Figure 43 presents the obtained results on vertical plane along the longitudinal aisle on the south side with the natural smoke exhaust system and permanent smoke barriers along the edges of floor voids. In comparison with Figure 42, permanent barriers are as performing as temporary barriers. Indeed, L6 to L8 remain free of smoke. When smoke layer on L5 becomes thicker than barrier height, smoke spreads to the rest of the building. At 900 s, there is some smoke on L6 in the western part. The eastern part is "protected" by the floor void between L6 and L7. Smoke is on L7 and L8 in the upper part in the western part too. At 1200 s, like in scenario 13 with temporary barriers, smoke fills the overall building except the lower part on level L4.

Whereas temporary barriers are undoubtedly complicated to install, such barriers do not conduct to definitive better conditions within the building relative to permanent barriers. Moreover, permanent barriers present the interest to constitute a price when building is constructed but later, in the operating conditions, there is no maintenance and personnel does not need to be instructed of their use. Permanent are thus preferred. However, to limit smoke spread via the interconnection, barriers positioned at the edges of the floor voids are larger than the one along the open stairway on the south side. The goal is to promote smoke flow toward open stairways rather than toward floor voids.

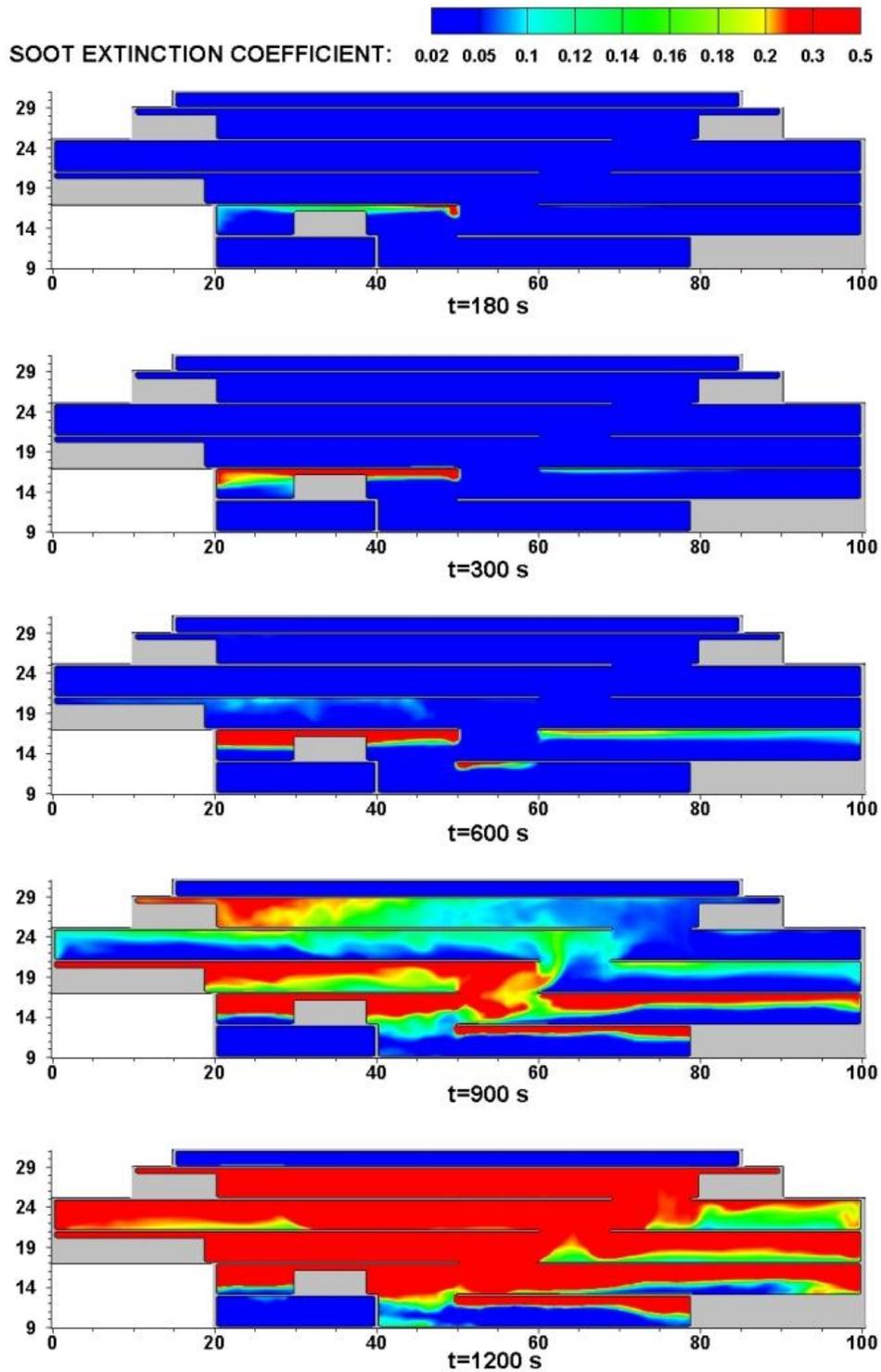


Figure 43: Extinction coefficient contour at given times at $y=10$ m, with the natural smoke exhaust system and permanent smoke barriers along the edges of floor voids (scenario 12)

3.5.5 EVACUATION WAYS

Despite the number of solutions tested to exhaust smoke, in case of fire II at least, conditions become unsafe for people after a while since each level from L5 up to L8 becomes totally smoke-filled and L4 partly smoke-filled. Thus, it appears necessary to allow people to safely and quickly leave the building or let them to reach a safe place, as fast as possible. In this idea, evacuation ways are designed. Building specifications define one stairway on the south side. However, since it is opened, it does not remain safe for people during their evacuation. Consequently, two additional stairways are positioned on the north side at two distant positions (cf. Figure 30). Each serves each level from L4 to L8. In this way, people have a stairway within a radius of 25 m wherever they are (cf. Figure 29) and at least two of them are safe at any time.

People on L5 to L8 who evacuate the building by going down by the stairways (enclosed or not) will need to take L4. Thus, it appears necessary to give priority to keep safe conditions on level L4. In order to let smoke spread and limit the height of smoke layer on this level, no smoke barrier is positioned along the open stairway on the south side. However, smoke barrier at the edges of the floor void between L4 and L5 is kept in order to limit smoke filling on L5.

In order to minimize the time necessary for egress and for going in safe place on level L8, four doors (two at east side and two at west side) allow to people to reach the terraces from workspaces and aisles. From these terraces, there is a direct access to the enclosed stairways at the north side with gates (cf. Figure 30).

3.6 EFFICIENCY OF THE RESULTING STRATEGY FOR THE OFFICE LEVELS

3.6.1 ASPECTS RELATED TO SMOKE FILLING

3.6.1.1 Influence of fire location in the building

Assessment of the influence of fire location in the building is based on each fire simulated since they are located on different levels. To illustrate our observation, fires IV and VI are used through the scenarios 29 and 31.

In all cases, smoke is hotter than ambient air, even slightly. This temperature difference induces smoke rises in the building. Consequently, when fuel is burning on a given level, despite the strong smoke dilution, smoke fills the levels above via the open stairway on the south side and the floor voids. For instance, in scenario 29, fire is located on L6 and smoke is present from L6 up to L8 at 1200 s; in scenario 31, fire is located on L7 and smoke is present from L7 up to L8 at 1200 s (cf. Figure 46 and Figure 48). It means that even the strong dilution, smoke does not flow to the levels below. In practice, levels below may remain free of smoke and also safe for people, levels above may remain free a smoke during a few minutes before being smoke-filled, partly of totally according the fire location on the level and its characteristics (HRR). In particular, when fire is located on L8, all other office levels are free of smoke and wherever the fire is located in the building between L4 and L8, there is a chance that level L8 is smoke-filled after a while. Thus, it appears that the level L8 must be evacuated rapidly and in all cases.

3.6.1.2 Influence of fire location on office level

Assessment of the influence of fire location on office level is based on each fire simulated since most of them are situated at different distances (close or far) from floor voids, open stairway, aisles and exits for evacuation. To illustrate our observation, fires II, III, IV, VI and VII are used through the scenarios 27, 28, 29, 31 and 32.

In all cases, smoke is hotter than ambient air, even slightly. This temperature difference induces smoke rises up to the roof. Then, it spreads horizontally until reaching an obstruction like a vertical wall or a smoke barrier. Also, when fuel is far from floor void, for instance, in scenarios from 29 to 32, smoke is first present in the upper part of the level where fuel is located (cf. Figure 46, Figure 48, Figure 47 and Figure 49). A smoke layer is created and becomes thicker. When smoke layer becomes higher than the height of the smoke barrier positioned along the stairway on the south side, smoke rises to levels above. When fuel is close to floor void, in scenarios 27 and 28, smoke rises to the level above via the floor voids and then to all levels in a short while (cf. Figure 44 and Figure 45). It means that efficiency of smoke barriers depends strongly on the fire location. It will be more performing when fire is in open workspaces, relaxation area or meeting rooms. It will be less performing when burning fuel is in storage space along floor voids or in workspaces under the floor voids. In other words, storage space along floor voids and workspaces close to the floor voids represent the riskiest zones for smoke filling.

3.6.1.3 Influence of HRR

Assessment of the influence of HRR is mainly based on fires V and VI which involve each a fire at the same location but releasing different rates of heat. At 1200s, fire VI releases three times more heat than fire V. In both scenarios 30 and 31, conditions are similar on the level where fuel is located, height of interface between smoke and fresh air is the same. The level above is filled of smoke in both cases. However, the volume of smoke on the level above lets suppose that when HRR is more important, more smoke is produced and also the levels above are smoke filled more quickly.

3.6.1.4 Influence of climatic conditions

Remark: Human resources implied in the present study have not been sufficient to conduct such assessment properly.

The indoor air temperature relative to outdoor value causes natural aeraulic flow in the overall building from top to bottom or the reverse. Smoke flow is yielded by convection. When HRR is high, gas temperature between air and smoke is larger. Smoke flow in that case is less sensitive to natural aeraulic flow in the building. In practice, smoke flow is influenced by the natural aeraulic flow rather at the beginning before HRR is sufficient.

Wind influences notably the efficiency of natural ventilation. It could prevent smoke from leaving the building or promote smoke dilution. Scenarios 30 and 35 illustrate the second type of influence:

smoke is more diluted with wind. Consequently, its volume is larger and its temperature is lower. Level where the fuel is located is thus more smoke-filled and the levels above too.

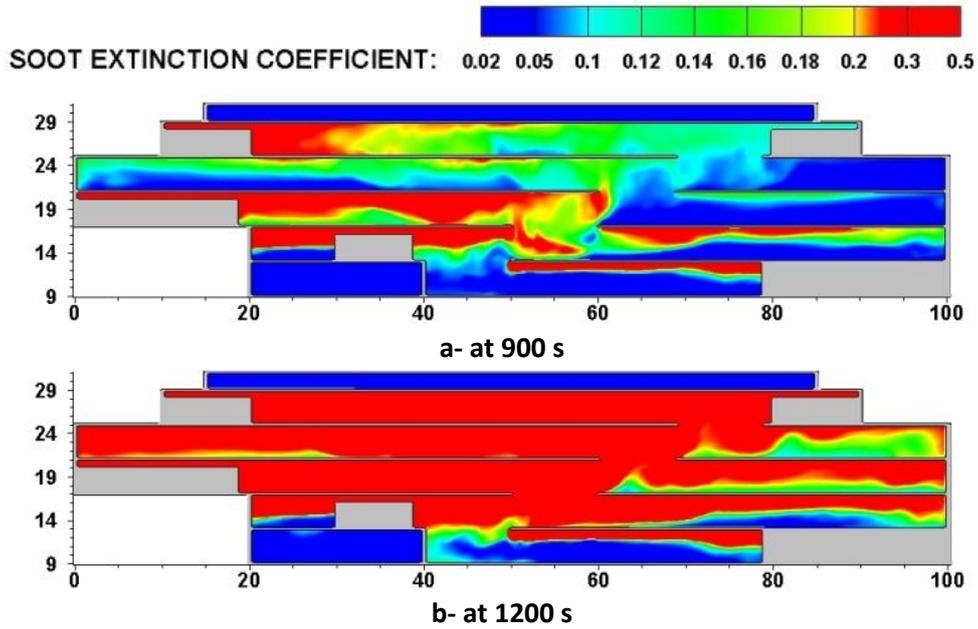


Figure 44: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 27)

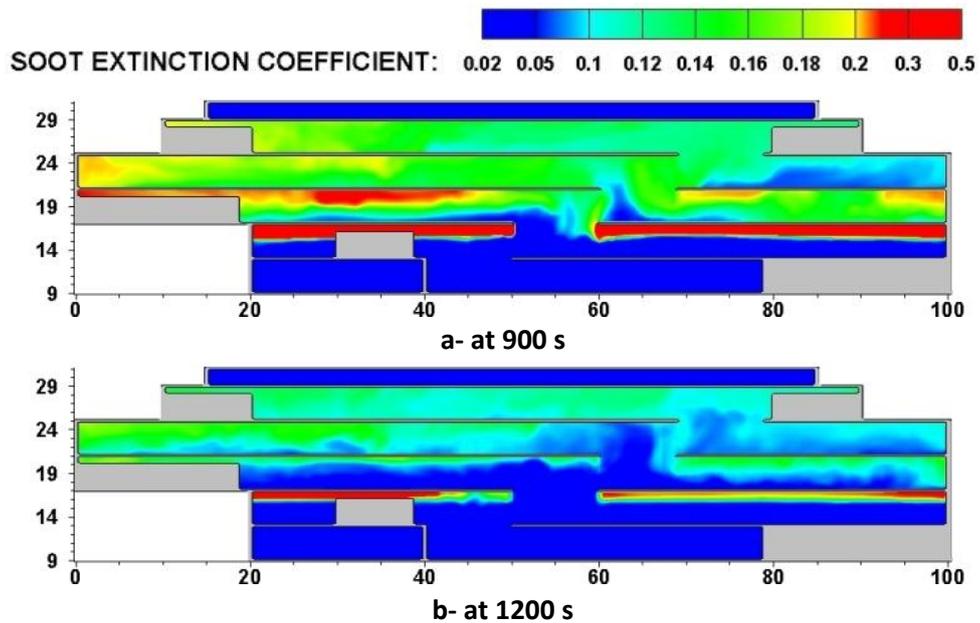


Figure 45: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 28)

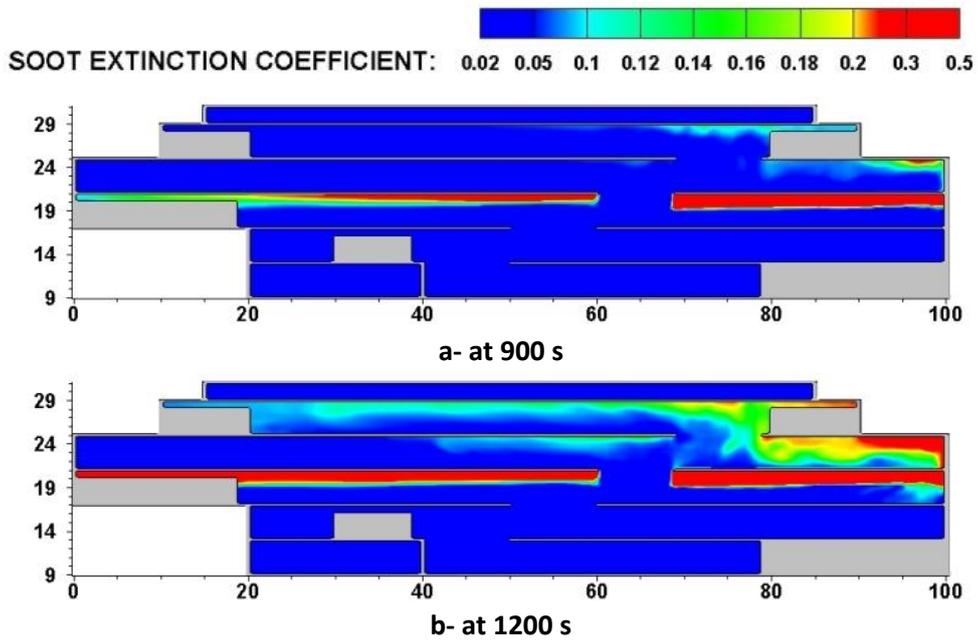


Figure 46: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 29)

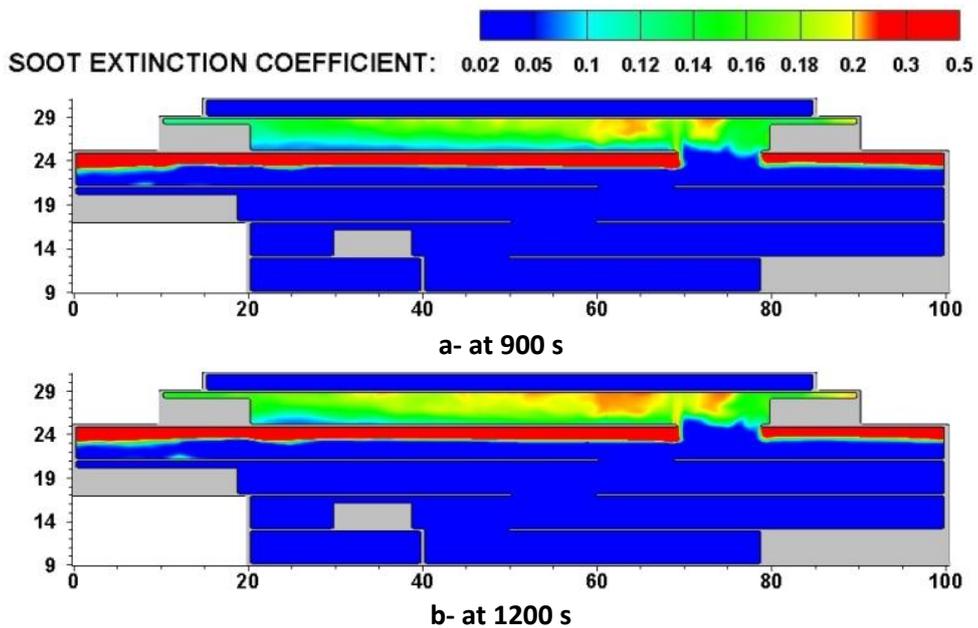


Figure 47: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 30)

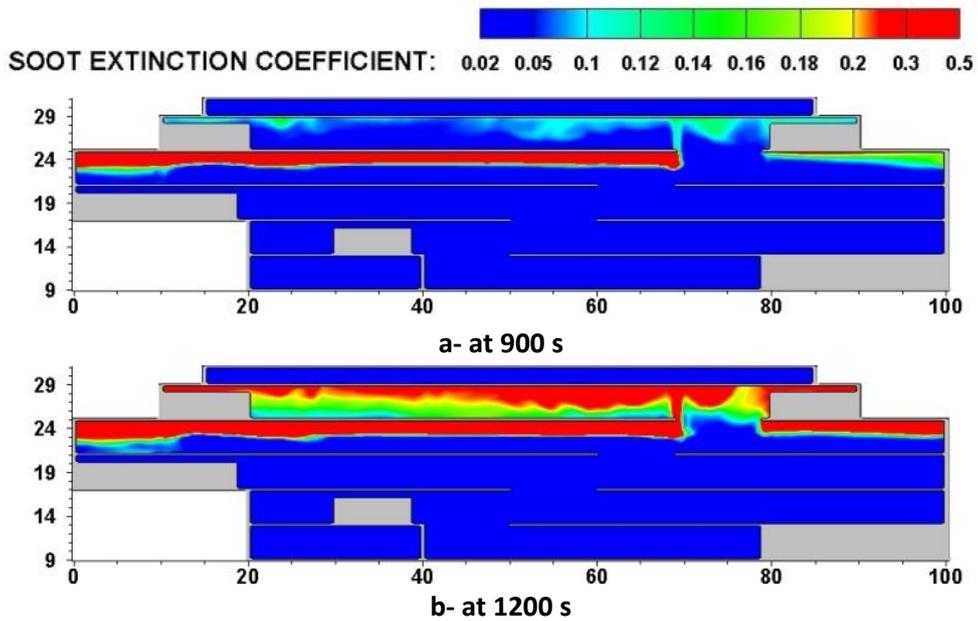


Figure 48: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 31)

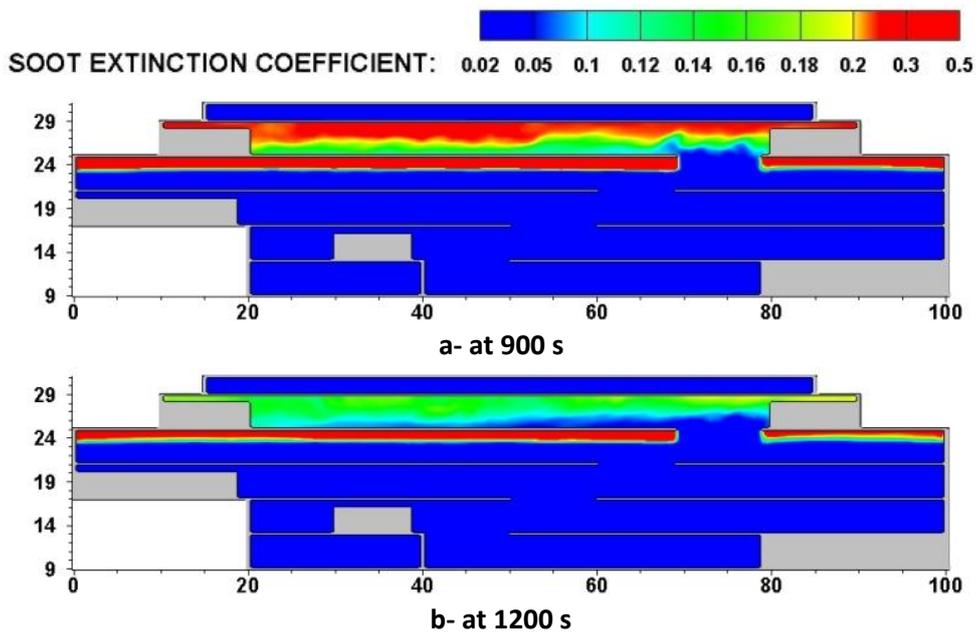


Figure 49: Extinction coefficient contour at y=10 m, with the resulting strategy (scenario 32)

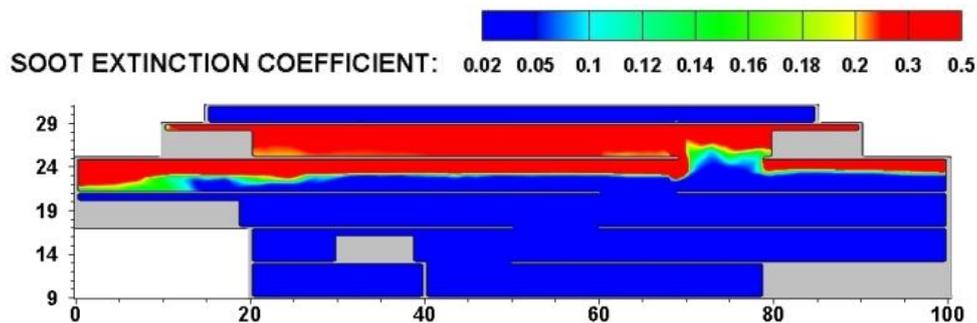


Figure 50: Extinction coefficient contour at $y=10$ m, at 900 s, with the resulting strategy (scenario 35)

3.6.2 ASPECTS RELATED TO FIRE RESISTANCE

Slabs, beams and columns of the building are made of reinforced concrete. Such structure must meet the French requirements relative to structural stability and fire resistance. In that frame, building structure is designed and constructed so that they can maintain their load-bearing function during fire duration. They are designed to limit fire spread too, in both cases where fire is located inside and outside the building.

The mechanical design and fire resistance of the building concrete structure follows the Eurocodes standards. Such design is not described here since they do not bring a real value-added to the present work. More specifically, the mechanical design and fire resistance of the building follows the Eurocodes EN 1992-1-1 (Règles générales et règles pour les bâtiments), EN 1992-1-2 (Règles générales - Calcul du comportement au feu) and EN 1991-1-2 (actions générales – actions sur les structures exposées au feu). It can be achieved using the software EC2 CIM'FEU developed by CSTB for design offices and technical controllers.

A qualitative fire risk analysis conduct to sort carparks, retails areas and office work spaces in the order where the thermal actions are likely the most significant and constraining.

For carparks, the severity of thermal actions is mainly due to the addition of three components: heat release rate of a burning vehicle that can reach or even exceed 10 MW, possible closeness of the fire place (parked vehicle) with structural elements (columns in particular) and last confinement (low ceiling) which increases the risk of fire spread. The fire stability requirement is defined by the French decree for covered Car parks dated May 9th, 2006 - Articles "PS".

Retails areas represent a small part of the building. Their surface areas do not exceed 1000 m². The requirement of structural fire stability is also set by the French decree of 22 December 1981 for sales stores and malls.

Last, for office workspaces, the results of the simulations based on various fire scenarios inside the building showed that the hot gas temperature, even on the fire concerned level, is relatively low: it does not exceed 120°C. This is largely due to the widely opened work spaces (open plan workstations) and the large number of interconnections between levels. The requirements for fire stability are defined by the Labor code.

3.6.3 ASPECTS RELATED TO FIRE PROPAGATION VIA THE FAÇADES

In accordance with the case study building specifications, the façades on east, south and west side of the office levels are glazed curtain walls. Such a material is extended to the façade on the north side as a consequence of the climate and our design guideline. More precisely, office level façades consist of double skin facade with the aims to meet this specification, limit building energy needs and ensure thermal comfort. Moreover, this double skin façade plays an additional role, namely in the fire safety strategy. Indeed, façades perform three functions: provide the most natural lighting in workspaces, regulate indoor conditions of occupants for comfort and exhaust smoke in case of fire.

Numerical simulations of fire scenarios showed that average temperature of hot gases is relatively low under the ceiling on the fire concerned level. For instance, it is below 150°C in scenario 29 involving fire IV (see Figure 51). On higher levels, it is less than 100°C and remains below the temperature reached on lower levels.

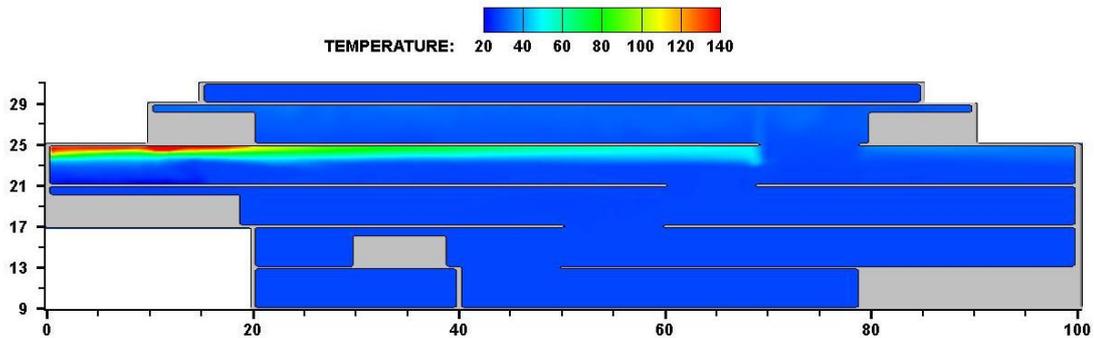


Figure 51: Temperature contour at 1200 s at y=10 m, with the resulting strategy (scenario 29)

Such temperature values are clearly insufficient to cause any damage to the glazing. Furthermore, both longitudinal aisle on the north side on each level and open stairway on the south side limit the façade fire spread risk by avoiding glazing to be directly subjected to fire flames. Concerning meeting rooms located on levels L5, L6 and L7 to the northeast, the meeting room on level L6, and open work spaces on west and east sides, thermal actions can be significant in case of fire in these spaces. Indeed, temperature may be high since they are semi-confined and they are situated in the direct vicinity of glazed curtain walls. One measure to reduce the risk would be building owner requires limiting fuel quantity along the wall or even avoiding fuel there.

To deal with this question, deeper study should be conducted for instance to quantify more precisely the possible thermal action. These simulations have not been carried out as part of this study due to the insufficient human resources.

3.6.4 ASPECTS RELATED TO PEOPLE EVACUATION

As detailed in Section 2.4.3, six simulations are run. Three door opening states are tested and two different furnishing configurations. Concerning door opening states, people evacuate by only one

enclosed stairway on the northeast side, by the two enclosed stairways on the north side or by the three stairways. Furnishing configurations involve either free spaces or furnished workspaces. The unfurnished configuration allows to estimate the occupant egress time depending only on the size of access doors, their position and the number of available doors. The two furnishing configurations allow to assess the influence of the internal layout on time duration for people evacuation. The following figure summarizes all the results. It shows the number of people who left the level versus time. That means at a given time, the value corresponds to the number of people qui has already evacuated the level by having access to the stairway.

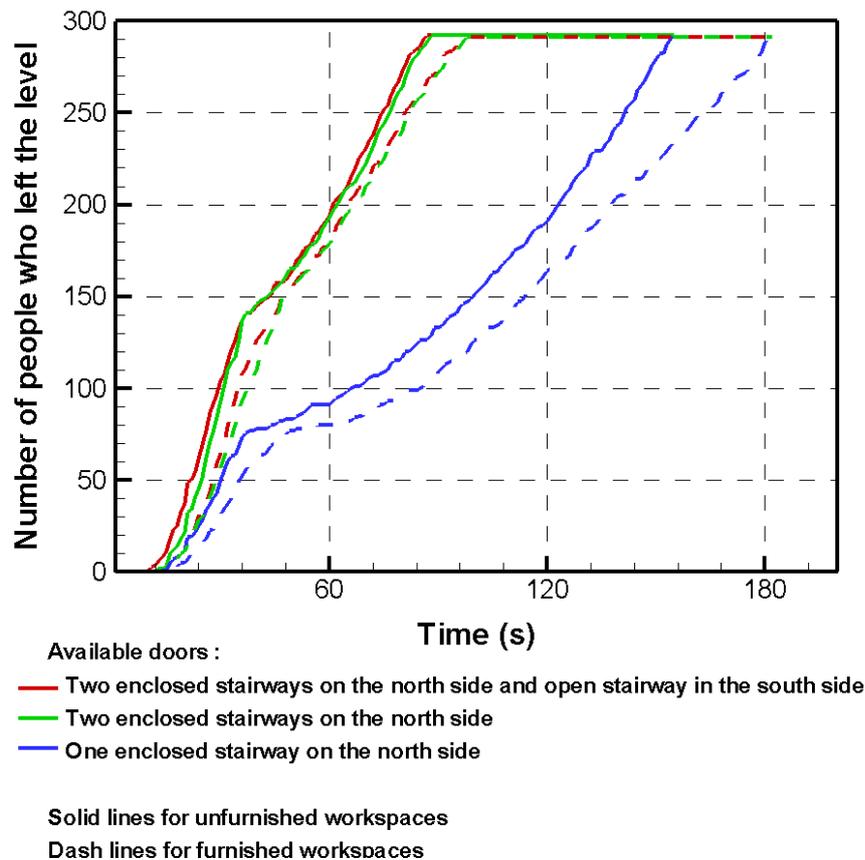


Figure 52: Number of people who left the level L6 versus time

Results show that only one single exit door conducts to the longest occupant egress time, it is about three minutes. With two exit doors, it is reduced by half and is close to one minute and a half. An additional exit at the south side does not provide a significant gain. This result can be explained by the occupancy: 292 persons are insufficient to congest exits. The three figures below illustrate this point. Thus, it appears that more occupants (several dozen more) will not necessarily contribute to an increase of egress time.

Moreover, results plotted on Figure 52 show that solid and dashed lines of the same color are almost superposed with more than two exit doors. It means the interior layout influences hardly people egress time when at least two stairways are accessible. With only stairway, there a difference of about 30 s for total egress time.

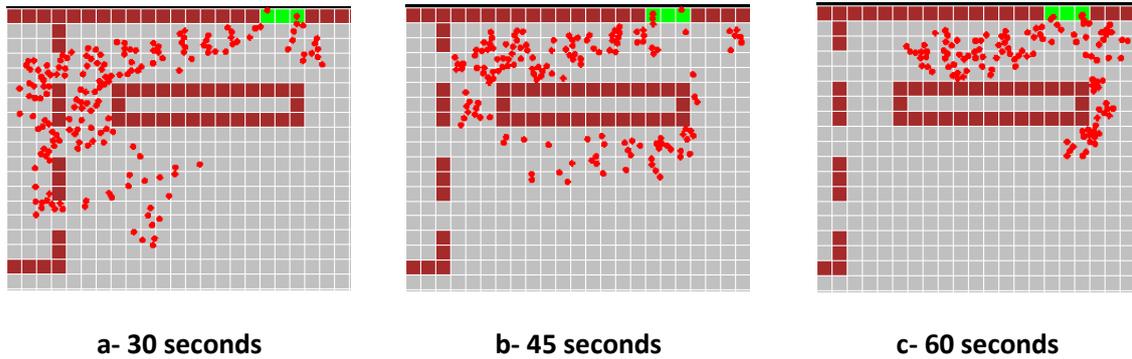


Figure 53: People positions at three times with two enclosed stairways on the north side (zoom on the northwest door)

Consequently, it appears important to keep clear all the three stairways at any time. If it is respected, the internal layout can be free. It is possible to suggest different interior layout without any impact on the egress time.

Finally, it should be kept in mind that these simulations assume that every occupant evacuate “ideally”. In other words we assume they evacuate at the initial time without any delay and choose the shortest path in distance to get the exit. As it is reasonably foreseeable, egress time would be in reality longer. Indeed, it is necessary to take into account more complex human behavior. Consequently, the calculated durations can be considered as the shortest duration to evacuate. A more precise computation should add a pre-movement period depending on human behavior.

3.6.5 INCIDENCE ON THE OPERATING PROCEDURES

Influences of fire location in the building, fire location on office level, HRR and climatic conditions lead to take the following decisions concerning the operating procedures in case of fire. When a fire occurs, it is detected by smoke detectors or it is signaled by people with glass break detector. Alarm is activated at the same time. A message is preferred rather than a sound. Without any delay, all the building is evacuated and all the bands integrated in the façades are opened to evacuate smoke. The personnel are informed and formed to their role: they should help people to evacuate, verify the integrated bands are opened, call the fireguards and attempt to extinguish fire when it is feasible with their equipment. The three stairways must be signaled, accessible and practicable for people evacuation. In case of wind (wind amplitude would need to be evaluated), bands located on the façade incident to wind should remain closed.

CONCLUSION

The present study deals with the exercise proposed by the 10th International Conference on Performance-Based Codes and Fire Safety Design Methods. It demonstrates the possibility to use the same equipment (double skin façade) to ensure dual roles, both for energy efficiency and in fire safety. In comparison with more current buildings where design regulations are independent and thus applied independently, the added value of such a solution is real, for technical, economic and environmental reasons.

The present study demonstrates the feasibility to adopt a combined approach to design a building performing in energy efficiency, thermal comfort and fire safety. Heat wave and fire ignition constitute such scenarios allowing to choose and to design equipment and materials the most appropriate for the building.

The use of dynamics simulators (CFD code, Fire Dynamics Simulator here) allows to quantify global building performance on thermal and energetic aspects. Moreover, it allows to meet the fire and life safety goals.

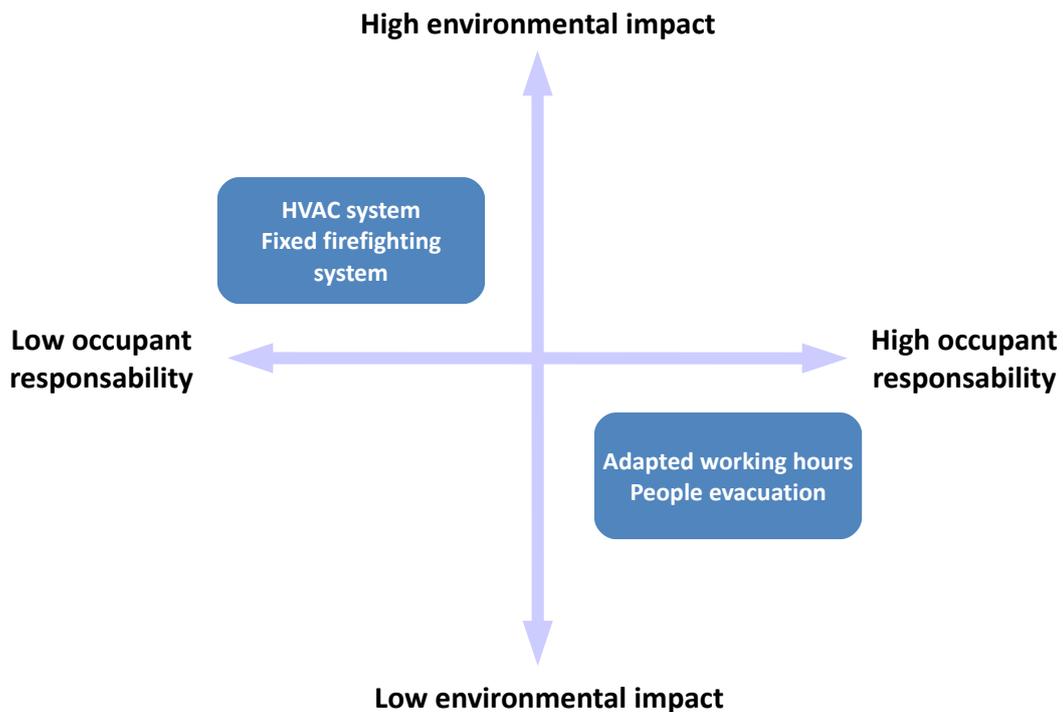
The final design on office levels, result of the present study, has the following characteristics:

- The five office levels are open. There is a minimum number of dividing walls. These levels are interconnected by floor voids promoting
 - air flow on the overall office levels,
 - smoke dilution and smoke flow which induce low smoke temperature and avoid presence of smoke on intermediate office levels,
- The structure is made of concrete without any floor covering and continuous suspended ceiling, promoting
 - people thermal comfort since it is capable to store and release heat thanks to a strong thermal inertia, it also permits to regulate indoor temperature,
 - a sufficient performance in fire resistance,
- The facades are glazed curtain walls, they are double skin façades promoting
 - natural lighting of workspaces and heat fluxes between indoor and outdoor compatible with office work,
 - sufficient smoke exhaust in case of fire.

For fire safety, three additional measures are proposed

- Two additional stairways on the north side. They are enclosed. They also remain safe at any time for people and personnel who want to go down to level L4 to evacuate,
- Smoke detectors distributed on each office level in order to react as early as possible,
- Frequent fire practice, they are important for occupants and for personnel. Indeed, occupant must be trained to evacuate the building in case of emergency. Personnel needs to have a dedicated education and a perfect knowledge about the building, its material, they must be familiar with the procedures.

The following table details the operating conditions of the double skin façade in normal use (current building occupancy, under normal conditions of temperature for the season, without fire) and in degraded use (heat wave, overcrowding building or with a fire). The table presents for summer, i.e. the most critical season according a thermal comfort approach in our context, the possibilities of the final design with a performance-based approach in both energy efficiency and fire safety. The present study allows to identify operational limits of the building design and in particular of the double skin façades. It identifies indoor conditions beyond which office work is no further guaranteed and lists technical and organizational measures which can be applied in complement or alternatively. For instance, working hours could be limited during heat wave or even an HVAC system can be installed. The last measure presents the advantage to ensure office work regardless of outdoor conditions. Such a system is comparable to fixed firefighting system in fire safety. These measures dedicated to maintain activity in degraded conditions can lay the basis for an analysis economic (installation and maintenance costs of devices which are used rarely), environmental (carbon footprint) and societal (occupant responsibility). The following figure illustrates the opinion of the authors.



Finally, the present study proposes an alternative to solutions relying only on technical measures to ensure energy efficiency, thermal comfort and fire safety. To apply it, dialogue with all stakeholders (occupant, owner, authorities) appears necessary. A survey conducted in 2005 about quality of work life shows only 21 % of people who usually work in an open space are totally satisfied². Other studies

² « Travail et sécurité », Dossier, Juillet-aout 2009

concerning adaptive comfort³ lay the emphasis on more flexible comfort line and thus a better people tolerance to ambient temperature when people is free totally or even partially to manage temperature with the possibility to open windows, to put down blinds, to wear more informal wears (free dress code) or to modify temporarily working hours. To answer to the opening question rose in the introduction of the present report “to build or not to build a 50 000 m³ open space?”, the solution should be analyzed by making profit of the studies about working conditions and working adaptation to manage degraded conditions for these specific open spaces.

Period	THERMAL CONFORT			FIRE SAFETY
	In normal conditions	In degraded conditions		In case of fire ignition
		Heat wave (two consecutive days with Text >20°)	Overcrowded building	
Summer during the day	<ul style="list-style-type: none"> - Heat storing by concrete slabs - Bands closed on interior façade - Bands opened on exterior façade - Venetian blinds put down 	<ul style="list-style-type: none"> - Band openings monitoring to get no air circulation within the layer - Adapted working hours, individual fan, HVAC system 	<ul style="list-style-type: none"> - Band openings monitoring to get no air circulation within the layer - Individual fan, HVAC system 	<ul style="list-style-type: none"> - Evacuation of all people - All bands opened on both interior and exterior façades - Fixed firefighting system
Summer during the night	<ul style="list-style-type: none"> - Concrete slab cooling - All bands opened on both interior and exterior façades - Venetian blinds opened 	No work during the night	No work during the night	<ul style="list-style-type: none"> - All bands opened on both interior and exterior façades - Fixed firefighting system

Table 8: Use of the double skin façade in normal conditions and in degraded conditions in summer (for thermal comfort and fire safety)

³ J.F. Nicol, M.A. Humphreys, Adaptive thermal comfort and sustainable thermal standards for buildings, energy and buildings 34 (2002) 563-572

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