Case Study Building Specifications

High-Rise Health Care Facility

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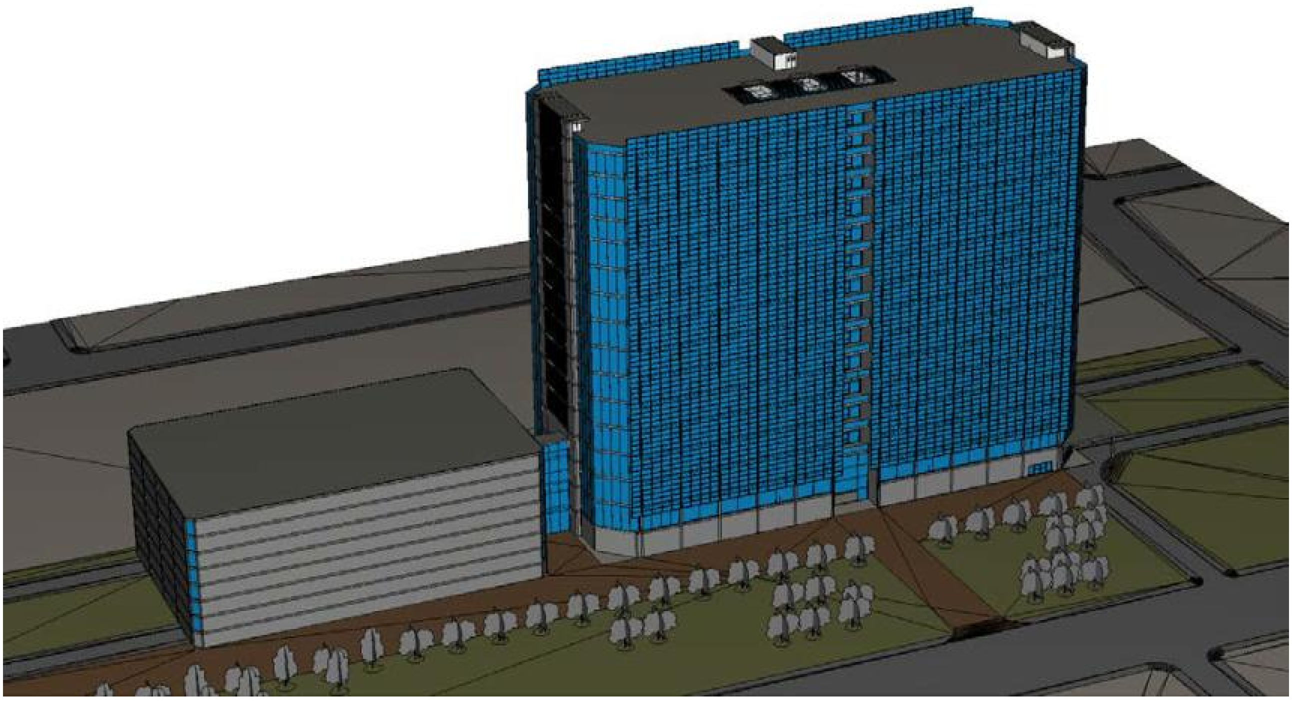

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1. Abstract

This paper presents a performance-based design for a new high-rise health care facility with associated parking garage. The building will contain both in-patient and out-patient care, medical offices, and supporting uses.

The design strategy to achieve the fire safety objectives includes the following key measures:

- Smoke compartmentation (REI60) to:
    - limit spread of fire and smoke
    - limit the number of occupants exposed to a fire
    - facilitate the horizontal relocation of patients
- Floor-to-floor openings are restricted to limit smoke spread between floors;
- Detection system throughout the building;
- Voice message alarm system to all floors to help performing the phased horizontal evacuation strategy and the defence-in-place strategy;
- Effective sprinkler system to control the development of the fire in some parts of the building (Offices, basement);
- Reliable automatic natural smoke venting system which extract smoke from the atrium;
- Mechanical smoke and heat control system for rooms in which there can be patients which cannot be moved in case of emergency (treatment rooms, intensive care units, cardiac care units, surgery rooms etc.);
- Evacuation lifts to guarantee a quick evacuation also on the upper floors;
- Rescue lifts for fire-brigade intervention;
- Phased evacuation strategy supported by a solid management system;
- Defence-in-place strategy for treatment rooms.

In this paper the design strategy suggested to reach occupant and fire brigade safety and minimize structural failures is described.

2. Introduction

This paper presents a performance-based fire safety design of a hypothetical case study proposed by the SFPE International Conference organisers; the described fire safety design is representative of Italy.

2.1 Building characteristics

The case study is a high-rise health care facility composed by 16 floors and a Basement level; in the building's central core there is an atrium. Adjacent to the hospital an 8-story parking garage is connected to the hospital on Levels 1-4.

The building plans are reported in **Annex A**. Following a description of the critical structural features assumed for occupants' safety is reported.

A minimum door and corridor widths is imposed to be capable of serving patients needing stretchers or gurneys for transportation; corridor widths accommodate wheelchairs as well.

On the two opposite sides of the building there are lifts among which, two are used for occupant's evacuation and one for rescue purpose. In **Figure 1** the configuration of the evacuation and rescue lifts for one of the two side of the building is shown.

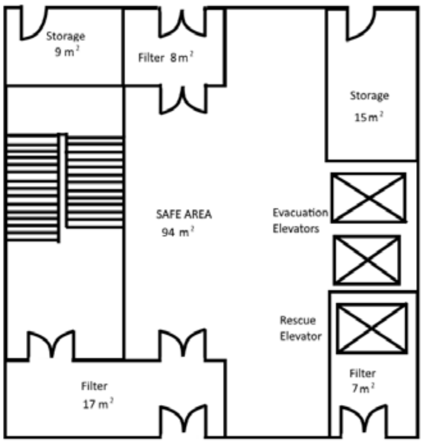


Figure 1 - Lifts' configuration

As shown in Figure 1, the access to each of the lifts takes place through a smoke filter. A filter is a fire compartment which has:

- fire resistance at least equal to 30 minutes;
- at least two doors E-30Sa with a self-closing device;
- specific fire load less than 50 MJ/m^2;
- pressurized with at least 30 Pa in case of emergency

Filters are used to guarantee that staircases, safe areas and elevators are maintained free of smoke in case of fire in the building; due to their sterile nature a fire in those areas is excluded.

For each floor there are two rescue lifts (one on each side of the building); those lifts are for exclusive use of fire-fighters, so they are completely independent from the rest of the emergency paths, so as to avoid interference between the intervention of the fire brigade and the evacuation of the building. The choice of installing two rescue lifts, one for each side of the building, guarantees the access to the fire brigade to every part of the building in case of emergency.
The rescue lifts are driven by a dedicated electrical system in such a manner to function even in absence of electricity.
In order to ensure the availability of the lifting system, even in case of improper use, a device automatically returns the cabin to the reference plane when the stop-time at a floor different from the reference one (level from which the emergency service enters) exceeds 2 minutes.
The rescue lift has a dedicated filter that guarantees a smoke free environment in the cabin.

The evacuation lifts instead are used from occupants in case of emergency; they have a fire resistance of 60 minutes and are protected by a filter so that can be used safely.

The Safe Area is a place in which there is no imminent danger for the occupants and guarantees that, in case of fire, people can stay there or be in transit in it.

Due to the fact that building façades are considered as one of the critical elements in case of fire, a dedicated study on the facades has been performed. Façade is the skin of the building which keeps it separated from the external environment, but where poor performance façades are built, a severe fire spread and building damage including human loss can happen.

Glass façade has been selected due to its characteristics such as durability, better appearance and indoor environment with daylight. However, the usage of glass façade brings a challenge due to the fact that fire and smoke can spread to upper floors through broken openings.

The possibility to install double-skin facades has been considered; a CFD simulation has been done to analyse the fire spread from one floor to another due to a fire in a room. The analysed double-skin façade is composed of two glass skins separated by a significant amount of air space, the thickness of the cavity is of 2 m. The double skin façade situation is described in **Figure 2**. In the simulation it has been supposed that a fire starts on the bottom floor and if, eventually there will be a flashover, a vertical spread will possibly occur by flames breaking out of the room and reaching the upper floor at high temperature.

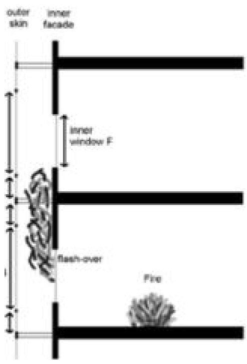


Figure 2 - Double-skin facade

When glass is exposed to fire and smoke, temperature differences will increase between the heated glass area and the edge area. As a result, thermal stresses develop increasingly due to temperature differences, and the glass pane will break and even fall out at a certain level.

Toughened glass (or tempered glass) is unlikely to break out until after the room fire has reached flashover (at about 600 °C). The Loss Prevention Council (LPC) studied double-glazed windows exposed to room fires and found that double-glazed windows using 6 mm thick floating glass would fail at about 600 °C. Recent experiments show that double-layer toughened glass break out at a temperature of about 600 °C–800 °C. [1]
It has been concluded that due to the installation of double-skin glass facades, there is an additional risk of stack effect in the air cavity that may accelerate the fire and smoke spread to upper floors. Thanks to the analysis, a single glass façade has been selected for the structure.

3. Fire Risk Assessment

A fire risk assessment has been developed applying three different methods:

- FLAME Method: developed by Fiorentini, Marmo and Danzi (Eade-EPC software)
- Italian Fire Code D.M. 3/8/15: With the “Fire Code D.M. 3/8/15” the performance-based approach has been introduced in Italy
- NFPA 101 Life Safety Code

3.1 Fire Level Assessment Matrix for Enterprises (FLAME)

Nomenclature

IPC	Ignition Probability Class
FGC	Fire Growth Category
EL	Exposure Level
PMT	Pre-movement time
RSET	Required Safe Egress Time
ASET	Available Safe Egress Time
ORL	Occupant Risk Level
FLC	Fire Length Category
FS	Fire Severity Level
FFE	Fire Fighting Expediency
FFM	Fire Fighting Means
CC	Compartment Configuration
PRL	Property Risk Level
PCL	Protection Category Level
ALL	Alert system

FLAME is a new method intended for the estimation of fire risk in workplaces. The method is a semi-quantitative parametric code that enables the quick evaluation of the acceptability of fire safety measures adopted in front of the severity of fire risk.

FLAME takes inspiration from some performance-based codes like Gretener [2], FRAME [3] and FRA-Mini ([4], De Smet, 2013), but applies strongly to the Italian more recent legislature in fire safety. The method goes back to the Fire Safety Concept Tree and has the typical structure of fire risk indexing methods.

With respect to other methods, FLAME has a specific feature: the differentiation among the indexes pools used for different targets (i.e. humans and assets). This allows the definition of specific fire risk values for different targets, different acceptability criteria with the subsequent evidence of the measures to be adopted to reach an adequate fire safety level. The fire risk level in FLAME is given by the combination of the factors that increase fire severity and the elements that contribute to mitigating fire hazards. An important aspect of this approach is the combination of both hard and soft factors, i.e. related respectively to structural or management parameters to describe the risk level. The risk is then defined as a function of fire load, fire typology, people vulnerability and exposure to fire, structural characteristics of the building, mobile or fixed protection equipment, escape system and organizational procedures in case of emergency.

Besides the key elements describing fire hazard, scores are assigned to fire protection (active and passive) measures so that fire safety management aspects can be evaluated against specific indexes to reduce or confirm negative performances.

Fire protection scoring is made through the definition of Protection Categories. This approach, here applied to fire safety assessment (in line with FRA-Mini, [4]) derives from standard EN-ISO 14121-1:2007 and ISO-EN 13849-1, respectively [5] and [6].

Throughout the process, the method includes weighed checklists, matrices, simplified algorithm applications and implementation of the basic concept of fire safety engineering. Its validation comes along with the references adopted for each steps of the evaluation. Fire safety basic elements are included in FLAME as concepts derived from the milestones of fire safety science at global level: SPFE Handbook [5] and Karlsson and Quintiere's publications [7], [8] have been adopted to idealize the structure behind the software.

Ignition frequency is defined according to the statistical study made in Finland by Tillander and Rahikainen [9], [10] and in Sweden by Sandberg [11].

The Required Safety Egress Time for occupants (RSET) is adopted by FLAME as a key-node of the evaluation process; before the publication of the new Italian Fire Code [12] (D.M. 03/08/2015) this concept was not included among the relevant elements in recent standards in Italy. The RSET estimate have been derived from the work of Marchant and Sime [13], [14] in particularly, but the basic concept could be traced back to several international standards that incorporate this approach already. Among them, the New Zealand Building Code ([15], Ministry of Business Innovation and Employment, 2013), the Building Code of Australia [16], and standards ISO TR 16738:2010 [17] and PD 7974:2004 [18].

FLAME structure is a logical, systematic flow where fire main elements and issues can be defined through several parameters, classified into categories (according to the intensity level of the parameter) and combined with each other: two different logical flows are employed for occupants and property risk definition. The dual evaluation of the method guarantees the possibility to obtain a more specific and effective evaluation of required safety level for the safeguard of people as for the tenability of structures. As an example, fire load parameter is not a key parameter to be taken into account for occupant's risk estimate (but only for the property). This because the most severe condition for people in a burning compartment is related to the velocity at which the conditions in the room are no more tenable for their life safeguard and thus disregarding the total amount of combustible materials present.

The fire load will instead be a key factor determining the risk for structures if a flashover, due to the huge amount of combustible materials, occur. The flashover conditions clearly should occur when the occupants of the compartment have already evacuated the compartment that is the origin place of the fire or the adjacent compartments.

The probability of fire ignition is considered one key-factor as assessing occupant risk, while it is not a critical factor in the property risk evaluation chart. The differentiation concerning property evaluation is well understandable: if people safety is concerned, the sooner the evacuation can take place, the safer the compartment. Meanwhile, a fast fire, involving a scarce fire load, is considered more dangerous than a slow fire involving a significant fire load. Consequently, occupant algorithm is time-based and the fire load parameter hasn't got any influence here (while for property the worst case will be that with a higher fire load). On the contrary, it is relevant to assess whether efficient ignition sources are present in the compartment and how strongly they influence the fire spreading, once it ignites.

The workflow adopted by FLAME is presented in **Figures 3** and **4**, respectively for Occupant Risk and Property Risk evaluation.

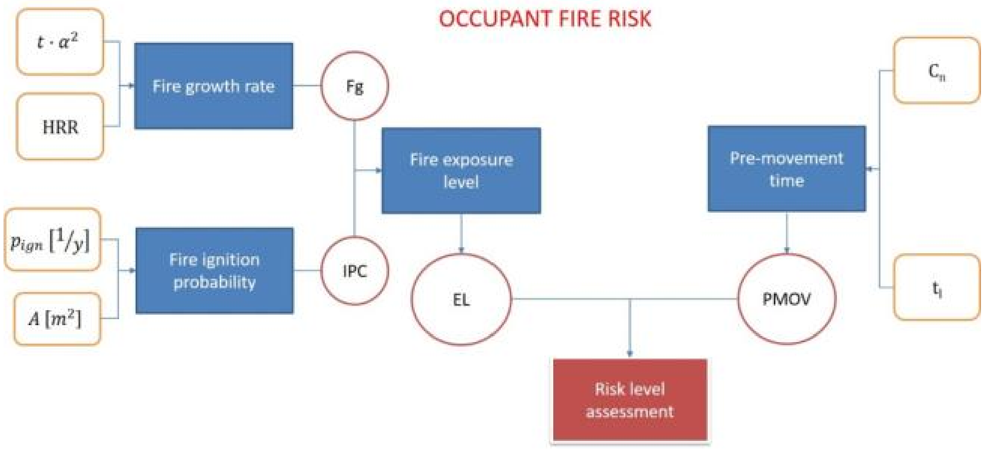


Figure 3 – Workflow for Occupant Risk

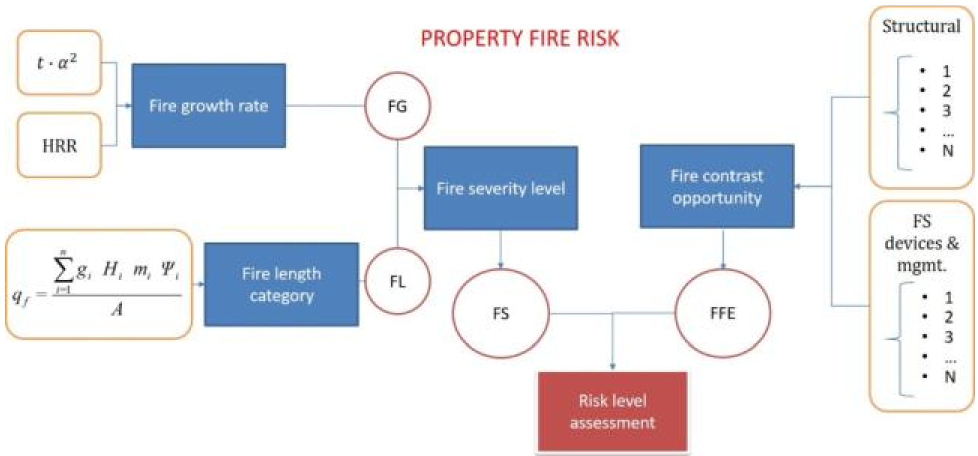


Figure 4 – Workflow for Property Risk

Occupant Risk Level (ORL) is obtained from the combination of scores from Fire Exposure and Pre-Movement Time nodes (EL and PMOV), through the matrix reported in **Table 1**:

Table 1 – Matrix of Occupant Risk Level (ORL)

EL/PT	EL1: Very Low	EL2: Low	EL3: Medium	EL4: Enhanced	EL5: High	EL6: Very High
PMT1	ORL1	ORL1	ORL2	ORL2	ORL3	ORL4
PMT2	ORL1	ORL2	ORL2	ORL3	ORL4	ORL5
PMT3	ORL2	ORL2	ORL3	ORL4	ORL5	ORL6
PMT4	ORL2	ORL3	ORL4	ORL5	ORL6	NA
PMT5	ORL3	ORL4	ORL5	ORL6	NA	NA
PMT6	ORL4	ORL5	ORL6	NA	NA	NA
PMT7	ORL5	ORL6	NA	NA	NA	NA

ORL is classified in 6 levels, from 1 to 6, and a Non-Acceptable (NA) level of risk is also defined, when exposure conditions or occupant characteristics are such to compromise people safety and no measures could mitigate risk. Italian Code, according to legislation in the fire safety field (D.M. 10/03/1998) defines risk as Low, Medium, High respectively if:

- Workplace in which no flammable substances are present, structural and occupational characteristics offer little probability of fire ignition and limited propagation.
- Workplace in which flammable substances are present and/or structural and occupational characteristics could be favourable to fire ignition, but where fire propagation has to be considered negligible;
- Workplace in which flammable substances are present, structural and occupational characteristics could be favourable to fire ignition, where strong probability of fire propagation in the initial phase is present.

In FLAME, this classification corresponds to levels ORL1 and ORL2 for Low, ORL3 and 4 for Medium and ORL5 and 6 for High.

Property Risk Level (PRL) can be then estimated from FFE and FS according to **Table 2:**

Table 2 – Estimation of Property Risk Level (PRL)

Fire Fighting Expediency/Fire Severity	FS1 Very Low	FS2 Low	FS3 Medium	FS4 Enhanced	FS5 High	FS6 Very High	FS7 Extra High
FFE4 High	PRL I	PRL I	PRL II	PRL III	PRL IV	PRL V	NAC
FFE3 Medium	PRL I	PRL II	PRL III	PRL IV	PRL V	NAC	NAC
FFE2 Low	PRL II	PRL III	PRL IV	PRL V	NAC	NAC	NAC
FFE1 Very Low	PRL III	PRL IV	PRL V	NAC	NAC	NAC	NAC

When FS is low, and FFE is adequate, the probability of a massive fire is low, whereas if a severe condition is expected and weak firefighting measures are in place the probability of an uncontrolled fire is high, with severe consequences and losses.
A Non-Acceptable Risk level is considered the case where protection Fire Fighting Expediency could not mitigate at all the Fire Severity, and more prevention measures are necessary to reduce the damage level.

FLAME method took inspiration from FRA-Mini to define a performance-based fire safety strategy where a performance level is estimated.

The Technical Standards behind this approach are [12] and [13]. Here a decisional tree combines severity, occurrence probability and exposure of a fire to define risk class, without any available protection measures. The standard considers five risk classes and [13] indicates the protection category coherent with the level of risk in order to mitigate it and/or reduce the risk (and the expected damage level) to an acceptable threshold value. Protection measures are divided in five levels of performance as depicted **Table 3**.
The different Protection Level (PL) are defined qualitatively according to the description reported below. The lowest PL is the Base Category, which stands for a "compliant with recent standards" equipment to Category 4, which considers the immediate report of each single failure of machine's components and the possibility to withstand also multiple damages through emergency devices. PRL at level V is acceptable only when associated to PL 4, while a lower risk could be mitigated by of lower categories. Base category is acceptable only at a peculiar condition.

Protection Category in FLAME assume similarly a score ranging from B (Base) to 4. This value depends on five aspects. The key-aspect concerns the technical firefighting system present in the compartment, as in **Table 3**. The other factors deal with protection level granted by:

- The emergency procedures planning;
- The fire safety management system;
- The housekeeping level and cleaning procedures;
- The maintenance and inspection level of firefighting means.

Table 3 – Protection categories

Protection Category	Technical elements	Emergency plan	Maintenance
B	Fire discovery left to occupants (voice alarm)	No Emergency plan	protection measures under surveillance
1	Manual fire alarm, with siren	No Emergency plan	Periodic check of firefighting means
2	Manual fire alarm and Public address (PA) system	Emergency plan	Periodic check of firefighting means
3	Automatic fire detection and PA	Emergency plan	Ordinary maintenance, fire-fighting service, high degree of cleaning and housekeeping
4	Automatic detection and extinction of fire	Emergency plan	Preventive maintenance on firefighting means, fire drill mandatory, maximum degree of cleaning/housekeeping

The Protection Category level (PCL) is set according to Technical element, as in **Table 3**. Organizational and Safety Management elements are required as well to maintain the PCL defined according to technical measures. In case of a missing element, PCL is downgraded to the highest value coherent with the organizational measure present. As an example, consider a compartment with manual fire alarm and a Public address (PA) system. Here the key-category associated to technical measures is PCL 2. This level would require the adoption of an emergency plan as well. If no Emergency Plan is adopted, PCL is downgraded to 1 (the highest level admitted with no emergency plan).

FLAME is strictly interconnected with the Italian requirements in the fire safety field. For this instance, any non-conformity found while estimating the Protection Category level with respect to Italian standards downgrade this level to "Non-adequate".

The last step of the process consists in the assessment of the adequacy of the fire safety management system respect to the risk level. This assessment is done in coherence with Italian and international recent prescriptions that request for a fire safety management system in case a performance-based approach is used. Besides the assessment of an acceptable threshold of risk is proposed, according to existing fire protection measures as described in **Figure 5 (a and b)** (both technical and organizational).

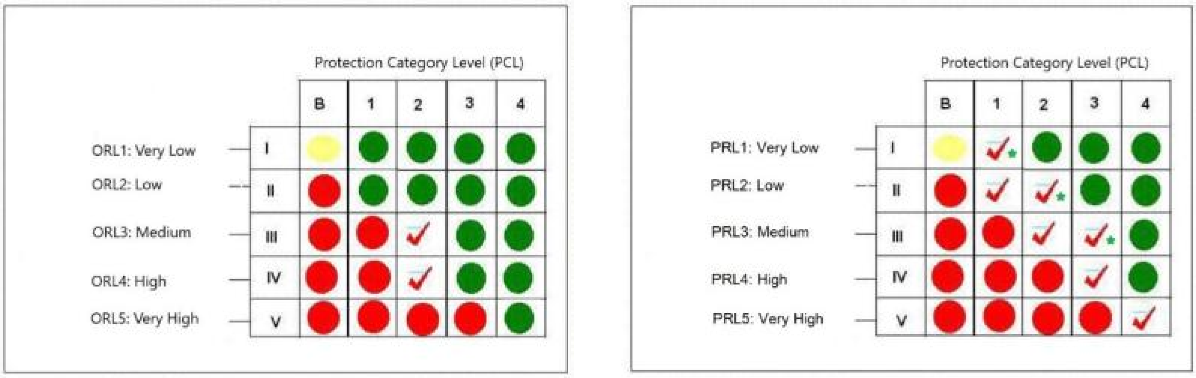


Figure 5 (a): Occupant Risk Level matrix and (b) Property Risk Level Matrix.

Four results can be obtained:

- Acceptable (A, green dots), the protection measures are compatible with the risk level;
- Not acceptable (NA, red dots), the protection measures could not face the severity of fire;
- Tolerable (T, red check): the protection measures could face the severity of fire, but still improving should be made
- Acceptable (A, yellow dot), peculiar case, concerning activity performed in a mono-compartment building.

As Property Risk Level is concerned 5 degrees of acceptability are considered:

- Acceptable (A, green dots), the protection measures are compatible with the risk level;
- Not acceptable (NA, red dots), the protection measures could not face the severity of fire;
- Tolerable (T, red check): the protection measures meet the necessary requirements with respect to the severity of fire, but still improving had to be made;
- Improvable (I, red check with green star): the protection measures could face the severity of fire, improvements are suggested;
- Acceptable (A, yellow dot), peculiar case, this is the case dealing with the mono-compartment activity.

3.2 FLAME application to case study

Each of the abbreviation on the Compartment column refers to a specific compartment of the building, the subdivision in compartments is reported in Annex B. In Chapter 8 a dedicated description of the compartmentation is shown.

Table 4: Compartment scoring, Occupant Risk flowsheet

Compartment	IPC	FGC	EL	ALL	PMT
BL-01	0	Fast	4	A3	3
L1-01	1	Moderate	2	A3	3
L1-02	1	Moderate	2	A3	4
L1-03	0	Medium	3	A3	3
L1-04	1	Moderate	2	A3	4
L1-05	1	Moderate	2	A3	4
L2-01	1	Low	1	A3	5
L2-02	1	Low	1	A3	5
L2-03	0	Medium	3	A3	3
L2-04	0	Medium	3	A3	3
L2-05	1	Medium	3	A4	3
L3-01	1	Moderate	2	A3	4
L3-02	1	Moderate	2	A3	4
L3-03	0	Medium	3	A3	3
L3-04	0	Medium	3	A3	3
L3-05	1	Moderate	2	A3	4
L3-06	1	Moderate	2	A3	4
L4-01	1	Moderate	2	A3	4
L4-02	1	Fast	4	A3	3
L4-03	0	Medium	3	A3	3
L4-04	0	Medium	3	A3	3
L4-05	1	Moderate	2	A4	4
L4-06	1	Moderate	2	A3	4
L5-01	1	Moderate	2	A4	4
L5-02	1	Moderate	2	A4	4
L5-03	0	Medium	3	A3	3
L5-04	0	Medium	3	A3	3

Table 4 (continues): Compartment scoring, Occupant Risk flowsheet

Compartment	IPC	FGC	EL	ALL	PMT
L5-05	1	Moderate	2	A4	4
L5-06	1	Medium	3	A4	4
L5-07	1	Medium	3	A4	4
L5-08	1	Moderate	2	A4	4
L6-01	1	Moderate	2	A4	4
L6-02	1	Medium	3	A4	4
L6-03	0	Medium	3	A3	3
L6-04	0	Medium	3	A3	3
L6-05	1	Medium	3	A4	4
L6-06	1	Medium	3	A4	4
L7-01 [*]	1	Medium	3	A3	4
L7-02 [*]	1	Medium	3	A3	4
L7-03 [*]	0	Medium	3	A3	3
L7-04 [*]	0	Medium	3	A3	3
L7-05 [*]	1	Medium	3	A3	6
L7-06 [*]	1	Medium	3	A3	6
L13-01 [**]	1	Medium	3	A3	3
L13-02 [**]	1	Medium	3	A3	3
L13-03 [**]	0	Medium	3	A3	3
L13-04 [**]	0	Medium	3	A3	3
L13-05 [**]	1	Medium	3	A3	3
L13-06 [**]	1	Medium	3	A3	3

[*] Since floors from 8th to 12th have the same compartment configuration and occupancy of 7th floor, they have been omitted from **Table 28** and followings.

[**] Since floors from 13th to 16th have the same compartment configuration and occupancy of 13th floor, they have been omitted in **Table 28** and followings.

Table 5: Occupant Risk Level and FLAME acceptability result

Compartment	Risk	PCL	FLAME result
BL-01	ORL3	4	A
L1-01	ORL2	3	A
L1-02	ORL3	3	A
L1-03	ORL3	3	A
L1-04	ORL3	3	A
L1-05	ORL3	3	A
L2-01	ORL3	3	A
L2-02	ORL3	3	A
L2-03	ORL3	3	A
L2-04	ORL3	3	A
L2-05	ORL3	3	A
L3-01	ORL3	3	A
L3-02	ORL3	3	A
L3-03	ORL3	3	A
L3-04	ORL3	3	A
L3-05	ORL3	3	A
L3-06	ORL3	3	A
L4-01	ORL3	3	A
L4-02	ORL4	3	A
L4-03	ORL3	3	A
L4-04	ORL3	3	A
L4-05	ORL3	3	A
L4-06	ORL3	3	A
L5-01	ORL3	3	A
L5-02	ORL3	3	A
L5-03	ORL3	3	A
L5-04	ORL3	3	A
L5-05	ORL3	3	A
L5-06	ORL3	3	A
L5-07	ORL3	3	A
L5-08	ORL3	3	A
L6-01	ORL3	3	A
L6-02	ORL3	3	A

Table 5 (continues): Occupant Risk Level and FLAME acceptability result

Compartment	Risk	PCL	FLAME result
L6-03	ORL3	3	A
L6-04	ORL3	3	A
L6-05	ORL3	3	A
L6-06	ORL3	3	A
L7-01 [*]	ORL3	3	A
L7-02 [*]	ORL3	3	A
L7-03 [*]	ORL3	3	A
L7-04 [*]	ORL3	3	A
L7-05 [*]	ORL3	3	A
L7-06 [*]	ORL3	3	A
L13-01 [**]	ORL3	3	A
L13-02 [**]	ORL3	3	A
L13-03 [**]	ORL3	3	A
L13-04 [**]	ORL3	3	A
L13-05 [**]	ORL3	3	A
L13-06 [**]	ORL3	3	A

Table 6: Compartment scoring, Property Fire Risk flowsheet

Compartment	FLC	FGC	FS	CC	FFM	FFE
BL-01	Medium	Fast	3	Easy	High	4
L1-01	Limited	Moderate	2	Easy	Good	3
L1-02	Limited	Moderate	2	Easy	Good	3
L1-03	Limited	Medium	3	Easy	Good	3
L1-04	Limited	Moderate	2	Easy	Good	3
L1-05	Limited	Moderate	2	Easy	Good	3
L2-01	Limited	Low	1	Easy	Good	3
L2-02	Limited	Low	1	Easy	Good	3
L2-03	Limited	Medium	3	Easy	Good	3
L2-04	Limited	Medium	3	Easy	Good	3
L2-05	Limited	Medium	3	Easy	Good	3
L3-01	Limited	Moderate	2	Easy	Good	3
L3-02	Limited	Moderate	2	Easy	Good	3
L3-03	Limited	Medium	3	Easy	Good	3
L3-04	Limited	Medium	3	Easy	Good	3
L3-05	Limited	Moderate	2	Easy	Good	3

Table 6 (continues): Compartment scoring, Property Fire Risk flowsheet

Compartment	FLC	FGC	FS	CC	FFM	FFE
L3-06	Limited	Moderate	2	Easy	Good	3
L4-01	Limited	Moderate	2	Easy	Good	3
L4-02	Limited	Fast	4	Easy	High	4
L4-03	Limited	Medium	3	Easy	Good	3
L4-04	Limited	Medium	3	Easy	Good	3
L4-05	Limited	Moderate	2	Easy	Good	3
L4-06	Limited	Moderate	2	Easy	Good	3
L5-01	Limited	Moderate	2	Easy	Good	3
L5-02	Limited	Moderate	2	Easy	Good	3
L5-03	Limited	Medium	3	Easy	Good	3
L5-04	Limited	Medium	3	Easy	Good	3
L5-05	Limited	Moderate	2	Easy	Good	3
L5-06	Limited	Medium	3	Easy	Good	3
L5-07	Limited	Medium	3	Easy	Good	3
L5-08	Limited	Moderate	2	Easy	Good	3
L6-01	Limited	Moderate	2	Easy	Good	3
L6-02	Limited	Medium	3	Easy	Good	3
L6-03	Limited	Medium	3	Easy	Good	3
L6-04	Limited	Medium	3	Easy	Good	3
L6-05	Limited	Medium	3	Easy	Good	3
L6-06	Limited	Medium	3	Easy	Good	3
L7-01 [*]	Limited	Medium	3	Easy	Good	3
L7-02 [*]	Limited	Medium	3	Easy	Good	3
L7-03 [*]	Limited	Medium	3	Easy	Good	3
L7-04 [*]	Limited	Medium	3	Easy	Good	3
L7-05 [*]	Limited	Medium	3	Easy	Good	3
L7-06 [*]	Limited	Medium	3	Easy	Good	3
L13-01 [**]	Limited	Medium	3	Easy	Good	3
L13-02 [**]	Limited	Medium	3	Easy	Good	3
L13-03 [**]	Limited	Medium	3	Easy	Good	3
L13-04 [**]	Limited	Medium	3	Easy	Good	3
L13-05 [**]	Limited	Medium	3	Easy	Good	3
L13-06 [**]	Limited	Medium	3	Easy	Good	3

Table 7: Property Risk Level and FLAME acceptability results

Compartment	Risk	Protection Category	FLAME result
BL-01	PRL2	4	A
L1-01	PRL2	3	A
L1-02	PRL2	3	A
L1-03	PRL3	3	I
L1-04	PRL2	3	A
L1-05	PRL2	3	A
L2-01	PRL1	3	A
L2-02	PRL1	3	A
L2-03	PRL3	3	I
L2-04	PRL3	3	I
L2-05	PRL3	3	I
L3-01	PRL2	3	A
L3-02	PRL2	3	A
L3-03	PRL3	3	I
L3-04	PRL3	3	I
L3-05	PRL2	3	A
L3-06	PRL2	3	A
L4-01	PRL2	3	A
L4-02	PRL3	3	I
L4-03	PRL3	3	I
L4-04	PRL3	3	I
L4-05	PRL2	3	A
L4-06	PRL2	3	A
L5-01	PRL2	3	A
L5-02	PRL2	3	A
L5-03	PRL3	3	I
L5-04	PRL3	3	I
L5-05	PRL2	3	A
L5-06	PRL3	3	I
L5-07	PRL3	3	I
L5-08	PRL2	3	A
L6-01	PRL2	3	A
L6-02	PRL3	3	I
L6-03	PRL3	3	I
L6-04	PRL3	3	I
L6-05	PRL3	3	I
L6-06	PRL3	3	I
L7-01 [*]	PRL3	3	I
L7-02 [*]	PRL3	3	I

Table 7 (continues): Property Risk Level and FLAME acceptability results

Compartment	Risk	Protection Category	FLAME result
L7-03 [*]	PRL3	3	I
L7-04 [*]	PRL3	3	I
L7-05 [*]	PRL3	3	I
L7-06 [*]	PRL3	3	I
L13-01 [**]	PRL3	4	A
L13-02 [**]	PRL3	4	A
L13-03 [**]	PRL3	4	A
L13-04 [**]	PRL3	4	A
L13-05 [**]	PRL3	4	A
L13-06 [**]	PRL3	4	A

3.3 Discussions of results

The evaluation of the fire risk related to occupants through FLAME returns an acceptable level of adopted safety measures in the totality of compartments individuated.

The most critical situations were found in compartments where patients could not evacuate by themselves, as operating suites, inpatients bedrooms, where an advances public address system has been adopted, capable of live emergency evacuation directives to staff and occupants of the compartment. This system allows to reduce significantly the pre-movement time and therefore the ORL associated to the compartment.

The acceptability of risk level of compartment situated in the basement floor is gained through the adoption of the automatic extinguishing system, which raise the Protection Category Level to the top level (4). The same is achieved in the compartment above the 12th floor, dedicated to medical offices, where again a sprinkler system is installed.

As what concerns the Property Risk Level, the acceptability deals with the adequate implementation of active and passive fire safety measures (Accounted in FLAME by the indexes CC and FFM). These two nodes contribute to define the Fire Fighting Expediency, which contrast the Fire Severity, which declines the capacity of fire to overcome the structure tenability.

The acceptability of the risk level is achieved with the adoption of 60’ fire resistant structures in all of the building, while only in the basement floor the fire resistance is raise to 90, due to the higher fire load present. The active fire safety measures adopted are: smoke barriers and natural smoke venting in all the height of the building, through the vent made up by the central atrium, which remove smoke and heat and released it to the top of the structure; adequate handling extinguishing devices; smoke detection all over the building; fire safety team available 24h inside the structure.

Sprinkler system grants the acceptability of Property Risk in basement compartment and offices compartments of floor 13th to 16th.

4. NFPA 101 – Life Safety code application

Nomenclature

M	Patient mobility factor
D	Patient density factor
R	Ratio patients to attendants' factor
A	Patients average age factor
S_1	Containment safety parameter
S_2	Extinguishment safety parameter
S_3	People movement safety parameter
S_4	General safety parameter
S_a	Mandatory containment parameter
S_b	Mandatory extinguishment parameter
S_c	Mandatory people movement parameter
R	Occupancy risk parameter

The fire safety evaluation is performed with the adoption of the Fire Safety Evaluation System, which is a measuring system that compares the level of safety provided by the fire safety measures adopted in a certain structure, to the level of safety provided in a structure that is in compliance with the prescriptions of the NFPA 101 code.

Chapter 4 of the Code deals with the evaluation of fire safety of health-care occupancies. A series of worksheet is provided to evaluate the level of safety step by step, following the FSES procedure.
The process could be done dividing the structure in defined Fire Zone, i.e. a space separated from others by floors, horizontal exits or smoke barriers. Typically, in a heath care facility are present similar arrangements throughout the building, the procedure suggest the inclusion of: zones with different patient type (defined by mobility, density or attendant to patient ratio); zone with significantly different type of constructions or finishing, zones with special medical treatment or support activities, zones not involving housing, treatment or access for patients.

In this analysis the fire zones are individuated in accordance to the compartmentation declined in Chapter 8, though similar arrangements (like compartments with patient housing or operating suites on the same floor) has been considered as a unique fire zone.

The procedure considers the following aspect of Occupant Risk: the patient mobility capability, the patient density, the floor factor, the patient to attendant ratio and the patient average age. Safety parameters considered are: the construction and interior finishing materials, zone dimensions, separations structures (doors and vertical openings), specific hazardous areas, smoke control, emergency movement routes, manual fire alarm, smoke detection and alarm, and automatic sprinklers.

A copy of the FSES worksheets is attached at this report.
The results of the evaluation are reported here, according to different fire zones.

Table 8: Occupant Risk parameter factors

Fire Zone	Risk parameters									
	Patient mobility (M)		Patient density (D)		Zone location (L)		Ratio patients to attendants (R)		Patient average age (A)	
Basement	Mobile	**1.0**	1-5	**1.0**	Basements	**1.6**	1-2/1	**1.0**	<65,>1	**1.0**
Outpatient clinics	Limited mobility	**1.6**	>30	**1.2**	2nd or 3rd	**1.2**	3-5/1	**1.1**	<65,>1	**1.0**
Inpatient rooms	Not mobile	**3.2**	>30	**1.2**	7th and above	**1.6**	6-10/1	**1.2**	<65,>1	**1.0**
Neonatology	Not mobile	**3.2**	>30	**1.2**	4th to 6th	**1.4**	6-10/1	**1.2**	>65,<1	**1.2**
Operating suites	Not movable	**2.0**	1-5	**1.0**	4th to 6th	**1.4**	1-2/1	**1.0**	<65,>1	**1.0**

Parameters used for the different compartments are highlighted in bold in Table 8 and 9.
As what concerns safety parameters, these were considered similar for all of the fire zones identified, with the only exception related to the presence of automatic sprinkler in the basement level and in the office compartments at the floor 13th to 16th. Different scores are also considered with respect to floor zones, according to the level where the examined fire zone is located.

Table 9 reports the safety parameters and their scoring.

Safety parameter	Parameter	Score
1. Construction	Non-combustible 222-322-433	**2** (**4** for floor higher than 1st)
2. Interior finish (corridors and exit)	Class A	**3**
3. Interior finish (rooms)	Class A	**3**
1. Corridors partitions/walls	≥1/2 h, <1h (fire resistance)	**1**
2. Doors to corridor	≥ 20' FPR and automatic closing	**2**
3. Vertical openings	Enclosed with indicated fire resistance ≥ 2 hrs	**3**
4. Hazardous areas	No deficiencies	**0**
5. Smoke control	Smoke barriers serves zone/Mechanical assisted systems by zone	**0/3 [***]**
6. Emergency movement routes	Multiple routes – Horizontal exits	**1**
7. Manual fire alarm	With Fire department connection	**2**
8. Smoke detection and alarm	Total spaces in zone	**5**
9. Automatic sprinklers	Corridors and habitable spaces/None	**8/0**

[***] Score 3 (mechanical assisted system for smoke control) is assigned only to compartments in which operating suites, impatient rooms and special treatment unit are present.

Safety parameters declined above concur in the definition of the individual safety evaluations, which are Containment safety (S1), Extinguishment safety (S2), People movement safety (S3) and General safety (S4).

Table 10 reports which parameters are considered in defining these indexes.

Safety parameter	Containment Safety (S1)	Extinguishment Safety (S2)	People movement safety (S3)	General safety (S4)
1. Construction	YES	YES	NO	YES
2. Interior finish (corridors and exit)	YES	NO	YES	YES
3. Interior finish (rooms)	YES	NO	NO	YES
10. Corridors partitions/walls	YES	NO	NO	YES
11. Doors to corridor	YES	NO	YES	YES
12. Vertical openings	NO	NO	YES	YES
13. Hazardous areas	YES	YES	NO	YES
14. Smoke control	NO	NO	YES	YES
15. Emergency movement routes	NO	NO	YES	YES
16. Manual fire alarm	NO	YES	NO	YES
17. Smoke detection and alarm	NO	YES	YES	YES
18. Automatic sprinklers	YES	YES	+2	YES

The equivalence to NFPA 101 code is made from an evaluation of the difference between Individual safety parameters and mandatory values for all the aspects, which are Mandatory containment (Sa), Mandatory extinguishment (S2), Mandatory people movement (S3). General safety (S4) is compared to Occupancy risk (R) obtained from the multiplication of occupancy risk parameters factors from Table 9.
If all the differences are > than 0 (i.e. all safety parameters overcome mandatory requirements) the evaluation is considered passed.

The mandatory safety requirements for our case are selected among those for new hospitals and they depend also on the floor or the fire zone examined and if the occupancy of it is characterized by sleeping or not sleeping patients. Table 11 reports the mandatory requirement parameters selected.

Table 11 Mandatory requirements parameters.

Fire zone	Location	S_a	S_b	S_c
Basement	4th story or higher (also used for underground level)	18	16	8
Outpatient clinics	2nd or 3rd story	15	14	7
Inpatient rooms	4th story or higher	18	19	11
Neonatology	4th story or higher	18	19	11
Operating suites	4th story or higher	18	19	11

Results are presented in Table 12.

Table 12 Results.

Equivalency evaluation	Fire zone				
	Basement	Outpatient clinics	Inpatient rooms	Neonatology	Operating suites
S_1-S_a	6	1	-1	-1	-1
S_2-S_b	2	-4	-8	-5	-5
S_3-S_c	10	7	7	10	10
S_4-R	30.4	19.8	17.7	16.1	22.7

4.1 Discussions

The FSES evaluation worksheet could give two different outputs: pass or fail, respectively a positive result among the differences calculated here in Table 11, column 1 to 5, or a negative result.
A “pass” result indicates that the level of the fire safety is at least equivalent to that prescribed by the Life Safety Code (NFPA 101), while at least one “fail” result among the different parameters indicate that there is some issues which do not allow the equivalence to the prescriptions of the Code.
The worksheet works well if applied to health-care facilities, where at least some patients are present and could not be used to evaluate compartment inside hospitals in which no patients are present (or allowed), such as medical offices, administrative offices, storages and laboratories. Fro this reason the compartments defined in this case study that individuate this type of occupancy could not be evaluated properly with this method.
Results obtained for the 5 fire zones individuated, which are chose among the most representative of the building (and could define more than one compartment analysed) indicates:

- A pass result for Basement level fire zone;
- A fail result for other fire zones

In particular, outpatient clinics received a negative result if Extinguishment parameter is considered, while inpatient rooms, neonatology, operating suites zones receive two negative grades associated to Extinguishment and to Containment safety parameters.
The reason for the failure in the equivalence to the Code is due to the absence of sprinkler automatic system, which has a great weigh in the accounting of extinguishment safety factor S_2 and also in the Containment Safety S_3, as could be observed in Table 9. The presence of a sprinkler system accounts for about the 24% on the parameter, while a minor weigh is defined as smoke mechanical control or detection alarm (respectively the 15% and 9%).
This logic of the FSES evaluation did result in a inadequate fire protection of hospital compartments with patients (sleep or awake) if a sprinkler system is absent; this although all other parameters are selected the best as possible, i.e. smoke detection all over the building, high grade of fire confinement structures, non-combustible material installed in corridors, finishing and rooms, high grade of emergency movement routes and smoke control in critical zones.

5. Italian Fire Code

The method applied as the main strategy for continuing the analysis of the fire safety design of the building has been the Italian Fire Code D.M. 3/8/15.
The main points which have been analysed for the new high-rise health care building are the following:

- **Means of warning and escape**: sufficient provision is made in the design of the building so that an early warning of fire can be given and the building occupants can escape to a place of safety.
- **Internal fire spread (linings)**: the internal linings of a building do not support a rapid spread of fire.
- **Internal fire spread (structure)**: the stability of the building structure is maintained for a reasonable period and the spread of fire through the building and in unseen cavities and voids is inhibited by subdividing the building with fire-resisting construction or the installation of automatic fire suppression.
- **External fire spread**: the spread of fire between buildings is discouraged by adequate separation between them and controlling the number and size of openings in the building envelope.
- **Access and facilities for the fire service**: the building, the site layout and access roads are designed in such a way as to enable the fire and rescue service to fight the fire and effect the rescue of persons caught in fire.

In Italy since 2015 a new Fire Safety Code has been introduced, which is aimed to overcome prescriptive rules. The Code contains technical requirements for a safety design of buildings. For the purpose of this case study, Italian decree D.M. 03/08/2015 is referenced.

Based on the Italian Code the occupants Risk profile has been related to Life Threat and Business Continuity. The Life Threat Risk Assessment is based on occupants' state of wakefulness, their familiarity with places etc. Coupled with the fire Heat Release Rate.

Table 13 (a) Occupants' categories (b) Fire's categories

Occupants characteristics δ_{occ}	
A	Occupants are awake and familiar with the environment
B	Occupants are awake and not familiar with the environment
C	Occupants might be asleep:
Ci	- Individual long lasting activities
Cii	- Management long activity
Ciii	- Management short activity
D	In-patient and out-patient occupants
E	Occupants in transit

Fire growing rate t_α	
1	Slow
2	Medium
3	Fast
4	Ultra-fast

In order to proceed with the building's design, the life risk (R_{life}) assessment has been determined for all type of rooms present in the Health-Care premise. The risk class is determined by the application of the following matrix.

Table 14 – R_{life} matrix

Occupants characteristics δ_{occ}		Fire growing rate			
		1 slow	2 medium	3 fast	4 ultra-fast
A	Occupants are awake and familiar with the environment	A1	A2	A3	A4
B	Occupants are awake and not familiar with the environment	B1	B2	B3	not admitted
C Ci Cii Ciii	Occupants might be asleep: - Individual long lasting activities - Management long activity - Management short activity	C1 Ci1 Cii1 Ciii1	C2 Ci2 Cii2 Ciii2	C3 Ci3 Cii3 Ciii3	not admitted
D	In-patient and out-patient occupants	D1	D2	not admitted	not admitted
E	Occupants in transit	E1	E2	E3	not admitted

Table 15 summarizes the R_{life} (Life risk) risk assessment for each occupancy on each floor; to be noted that each floor is characterized by the highest R_{life} between the calculated ones for the relative compartments.

Table 15 – R_{life} risk assessment

Floor	Room/Occupancy	δ_{occ}	δ_a	occ. R_{life}	Floor R_{life}
Basem.	storage, laundry, offices	A	4	A4	**A4**
1	offices	B	3	B3	**D2**
	patient rooms	D	2	D2	
	storage	A	4	A4	
	common spaces	B	3	B3	
2	offices	B	3	B3	**B3**
	auditorium	B	3	B3	
	cafeteria	B	3	B3	
	common spaces	B	3	B3	
3	treatment rooms	D	2	D2	**D2**
	offices	B	3	B3	
4	patient rooms	D	2	D2	**D2**
	laboratories	A	4	A4	
	physical therapy	D	2	D2	
	imaging rooms	D	2	D2	
5	surgery	D	2	D2	**D2**
	patient rooms	D	2	D2	
6	neonatology	D	2	D2	**D2**
	patient rooms	D	2	D2	**D2**
7	patient rooms	D	2	D2	**D2**
8	patient rooms	D	2	D2	**D2**
9	patient rooms	D	2	D2	**D2**
10	patient rooms	D	2	D2	**D2**
11	patient rooms	D	2	D2	**D2**

Floor	Room/Occupancy	δ_{occ}	δ_a	occ. R_{life}	Floor R_{life}
12	patient rooms	D	2	D2	**D2**
13	medical offices	B	3	B3	**B3**
14	medical offices	B	3	B3	**B3**
15	medical offices	B	3	B3	**B3**
16	medical offices	B	3	B3	**B3**

To be pointed out that in the following of the paper, the terms “*compliant solution*” are related to the specific requirements given by the DM 03/08/2015 in order to achieve the safety goals for fire prevention and protection; in case the compliant solution has not been practicable (i.e. due to various constrains or technical impairments), the decree DM 03/08/2015 admits the “*alternative solution*” referred to the Fire Safety Engineering approach (FSE).

6. Reaction to fire

Requirements regarding reaction to fire are evaluated according to Chapter S.1 of Italian DM 03/05/2015. The performance levels for the reaction to fire are reported in **Table 16**:

Table 16 – Performance level for reaction to fire

Performance level	Description
I	No requirements
II	Materials contribute in a non-negligible manner to the fire
III	Materials contribute moderately to the fire
IV	Materials contribute in a limited way to the fire

In **Table 17** and **18** the criteria to determine the performance levels are described:

Table 17 - Criteria of attribution of the performance level for exodus paths

Performance level	Criteria of attribution of the level of performance for exodus paths
I	Exodus paths not included in the other allocation criteria
II	Exodus path of compartments with Life-Risk (R_{life}) B1
III	Exodus paths of compartments with Life-Risk (R_{life}) B2, B3, Cii1, Cii2, Cii3, Ciii1, Ciii2, Ciii3, E1, E2, E3.
IV	Exodus paths of compartments with Life-Risk (R_{life}) D1, D2

Table 18 - Criteria of attribution of the performance level for other parts of the building

Performance level	Criteria of attribution of the level of performance for other part of the building
I	Premises not included in the other criteria.
II	The compartmental rooms Life-Risk (R_{life}) B2, B3, Cii1, Cii2, Cii3, Ciii1, Ciii2, Ciii3, E1, E2, E3.
III	Rooms of compartments with Life-Risk (R_{life}) in D1, D2
IV	On specific client's request, requested by technical project specifications or by the competent authority for buildings of particular importance.

The compliant solution for each performance level has been identified based on the following criteria, leading to the selection of appropriate materials:

- compliant solution for performance level II requires group GM3 materials;
- compliant solution for performance level III requires group GM2 materials;
- compliant solution for performance level IV requires group GM1 materials.

In the following Tables a classification of the reaction to fire for different materials is reported:

Table 19 – Reaction to fire classification for furniture, tents, ect.

Materials description	GM1	GM2	GM3
	Ita	Ita	Ita
Upholstered furniture (armchairs, sofas, sofa beds, mattresses, sommiers, pillows, topper, cushions)	1 IM	1 IM	2 IM
Bedding (blankets, bedspreads, mattress covers)	1	1	2
Furniture fixed and not to structural elements (chairs and seats not upholstered)			
Tents for tensile structures, pressostatic structures and mobile tunnels			
Curtains, drapes			
Scenic material, fixed and mobile scenery (wings, veils, curtains and similar)			

Table 20 – Reaction to fire classification for floor, wall and ceiling coatings

Materials description	GM1	GM2	GM3
	EU	EU	EU
Ceiling coatings	A2-s1, d0	B-s2, d0	C-s1, d0
False ceilings			
Raised floors (hidden surface)			
(1.5 m) Wall coatings	B-s1, d0		
Internal partitions, walls, suspended walls			
Floor coverings	B_{fl}-s1	C_{fl}-s1	C_{fl}-s2
Raised floors (walkable surface)			

Table 21 – Reaction to fire classification for floor, wall and ceiling coatings

Materials description	GM1	GM2	GM3
	EU	EU	EU
Protected insulation [1]	C-s2, d0	D-s2, d2	E
Linear protected insulation [1], [3]	C_L-s2, d0	D_L-s2, d2	E_L
Visible insulation [2], [4]	A2-s1, d0	B-s2, d0	B-s3, d0
Visible linear insulation [2], [3]	$A2_L$-s1, d0	B_L-s3, d0	B_L-s3, d0

[1] – Protected by non-metallic materials which belong to the group GM0 or products with fire resistance rating K10 and minimum reaction to fire class B-s1, d0;
[2] – Non protected as described in the previous note [1];
[3] – Referred to linear-shaped products for thermal insulation of ducts with maximum diameter 300 mm (including insulation).

Table 22 – Reaction to fire classification for plant materials

Materials description	GM1	GM2	GM3
	EU	EU	EU
Heating/ventilation ducts	A2-s1, d0	B-s2, d0	B-s3, d0
Insulated heating/ventilation ducts [1]	A2-s1, d0 B-s2, d0	B-s2, d0 B-s3, d0	B-s3, d0 C-s1, d0
Heating/ventilation ducts joints (L≤1.5)	B-s1, d0	B-s2, d0	C-s1, d0
Cables duct	[na]	[na]	[na]
Electrical/signalling cables [2], [3]	$B2_{ca}$-s1, d0, a1	C_{ca}-s1, d0, a2	E_{ca}

[1] – Double classification referred to pre-insulated duct with insulation not exposed directly to flames. The first classification is referred to the whole material, the second classification is referred to the insulating material;
[2] – Reaction to fire classification requested if cables are not contained in non-combustible materials;
[3] – Burning droplets classification d0 may be de-rated at d1 if cables are installed at the floor level;
[na] – not applicable.

According to the described criteria, in **Table 23** the Fire Reaction characteristics required for each floor of the building is summarized.

Table 23 – Reaction to fire requirement for the considered building

		S.1 - Reaction to fire			
Floor	**Room/Occupancy**	*Required performance level for escape ways*	*Compliant solution*	*Required performance level for other rooms*	*Compliant solution*
Basem.	Storage, laundry, offices	I	no req.	I	no req.
1	Offices	III	GM2	II	GM3
	Patient rooms	IV	GM1	III	GM2
	Storage	I	no req.	I	no req.
	Common spaces	III	GM2	II	GM3
2	Offices	III	GM2	II	GM3
	Auditorium	III	GM2	II	GM3
	Cafeteria	III	GM2	II	GM3
	Common spaces	III	GM2	II	GM3
3	Treatment rooms	IV	GM1	III	GM2
	Offices	III	GM2	II	GM3
4	Patient rooms	IV	GM1	III	GM2
	Laboratories	I	no req.	I	no req.
	Physical therapy	IV	GM1	III	GM2
	Imaging rooms	IV	GM1	III	GM2
5	Surgery	IV	GM1	III	GM2
	Patient rooms	IV	GM1	III	GM2
6	Neonatology	IV	GM1	III	GM2
	Patient rooms	IV	GM1	III	GM2
7	Patient rooms	IV	GM1	III	GM2
8	Patient rooms	IV	GM1	III	GM2
9	Patient rooms	IV	GM1	III	GM2
10	Patient rooms	IV	GM1	III	GM2
11	Patient rooms	IV	GM1	III	GM2
12	Patient rooms	IV	GM1	III	GM2
13	Medical offices	III	GM2	II	GM3
14	Medical offices	III	GM2	II	GM3
15	Medical offices	III	GM2	II	GM3
16	Medical offices	III	GM2	II	GM3

As illustrated in **Table 23**, reaction to fire classification for materials in escape ways will be of GM1 and GM2 groups, and reaction to fire classification for materials in the remaining parts of the building will be GM2 and GM3. Thanks to the put in place of materials of categories GM2 and GM3 it's guaranteed a low fire load to decrease the fire power.
The Italian Fire Code requires stricter fire reaction classification for escape routes in order to facilitate evacuation.

7. Fire resistance

The Italian Safety Code has been applied to define the minimum requirements of fire resistance for each floor and the final values are integrated with the consideration reported on Chapter 5, so as to require if necessary stricter values.

The definitions of performance levels for the fire resistance are reported in **Table 24**, according to the chapter S.2 of the Italian decree DM 03/08/2015.

Table 24 – Resistance to fire performance level

Performance level	Description
I	Absence of external consequences due to structural collapse
II	Maintenance of fire resistance requirements for a period sufficient to evacuate occupants in a safe place outside the building
III	Maintenance of fire resistance requirements for a period consistent with the duration of the fire
IV	Fire resistance requirements to guarantee, after the end of the fire, a limited damage to the building
V	Fire resistance requirements to guarantee, after the end of the fire, the maintenance of the total functionality of the building itself

The evaluation of the performance level for the considered building will be according to the criteria described in **Table 25**:

Table 25 – Criteria for attribution of the performance level for fire resistance

Performance level	Criteria for attribution
I	Construction operas, including services adjacent construction and related technological services/plants, where ALL following conditions are verified: - compartmentation respect other adjacent buildings, and structural separation between them have to be achieved (so that any structural failure does not damage the other constructions); - only a single responsible subject is admitted for the considered activity and only the following risk level are admitted: Risk for goods = 1; No significant risk for environment; - no fixed personnel assigned in the area, except for short time activities.
II	Construction operas or their parts, including services adjacent construction and related technological services/plants, where ALL following conditions are verified: - compartmentation respect other adjacent buildings; - structural separation between them have to be achieved (so that any structural failure does not damage the other constructions or, in case separation cannot be achieved, any structural failure does not damage the constructions itself); - only a single responsible subject is admitted for the considered activity and only the following risk level are admitted: Risk for life = A1, A2, A3, A4; Risk for goods = 1; No significant risk for environment; - occupant load not greater than 0.2 pp/m^2; - building occupants with no disabilities; - floor height between -5 m and 12 m.
III	Construction operas not described in the other criteria for attribution of performance level.
IV, V	This performance level are considered in case of specific Contractor requirements or in case of Authority Having Jurisdiction request.

The considered construction is characterized by the performance level **III**. On the basis of the Italian decree DM 03/08/2015, for compliant solution the minimum fire resistance rating is related to the design specific fire load $q_{f,d}$, according to **Table 26**:

Table 26 – Minimum fire resistance rating

Design specific fire load $q_{f,d}$ [MJ/m²]	Minimum fire resistance rating
≤ 200	No requirements
≤ 300	15
≤ 450	30
≤ 600	45
≤ 900	60
≤ 1200	90
≤ 1800	12
≤ 2400	180
> 2400	240

The design value of the fire load $q_{f,d}$ is defined as:

$$q_{f,d} = \delta_{q1} \cdot \delta_{q2} \cdot \delta_n \cdot q_f$$

where:

δ_{q1} is a factor taking into account the fire activation risk due to the size of the compartment (see Table 24);

δ_{q2} is a factor taking into account the fire activation risk due to the type of activity in the compartment (see Table 25);

$\delta_n = \Pi\, \delta_{ni}$ is a factor taking into account the different active fire-fighting measures (sprinkler, detection, automatic alarm transmission, firemen ...). These active measures are generally imposed for life safety reason (see Table 26);

q_f is the characteristic fire load density per unit floor area [MJ/m²].

Table 27 – Values for δ_{q1}

Compartment gross floor area A [m²]	δ_{q1}	Compartment gross floor area [m²]	δ_{q1}
A < 500	1.00	2500 ≤ A < 5000	1.60
500 ≤ A < 1000	1.20	5000 ≤ A < 10000	1.80
1000 ≤ A < 2500	1.40	A ≥ 10000	2.00

Table 28 – Values for δ_{q2}

Class	Description	δ_{q2}
I	Areas with low fire risk, in terms of ignition probability, flame spread and capability of emergency team/fire brigade to control the fire	0.80
II	Areas with moderate fire risk, in terms of ignition probability, flame spread and capability of emergency team/fire brigade to control the fire	1.00
III	Areas with high fire risk, in terms of ignition probability, flame spread and capability of emergency team/fire brigade to control the fire	1.20

Table 29 – Values for δ_{ni}

Minimum fire fighting measures		δ_{ni}	
fire control measures (according to chpt. S.6, DM 03/08/2015), minimum performance level III	indoor fire hydrants	δ_{n1}	0.90
	indoor and outdoor fire hydrants	δ_{n2}	0.80
fire control measures (according to chpt. S.6, DM 03/08/2015), minimum performance level IV	automatic water/foam system and indoor fire hydrants	δ_{n3}	0.54
	automatic firefighting system (different type) and indoor fire hydrants	δ_{n4}	0.72
	automatic water/foam system, indoor and outdoor fire hydrants	δ_{n5}	0.48
	automatic firefighting system (different type), indoor and outdoor fire hydrants	δ_{n6}	0.64
firefighting safety management system (according to chpt. S.5, DM 03/08/2015), minimum performance level II [1]		δ_{n7}	0.90
heat and smoke control system (according to chpt. S.8, DM 03/08/2015), minimum performance level III		δ_{n8}	0.90
detection and alarm system (according to chpt. S.7, DM 03/08/2015), minimum performance level III		δ_{n9}	0.85
firefighting operativity measures (according to chpt. S.9, DM 03/08/2015), with compliant solution for performance level IV		δ_{n10}	0.81
[1] firefighting emergency team must be continuously in service 24h/24h			

The fire load density (q_f) evaluation is based on a statistical approach (according to the provision of the Italian decree DM 03/08/2015), considering the 80% fractal values given by literature reference (ref. to NFPA Fire Protection Handbook, 20th edition, Table 18.1.6).

The design value of the fire load $q_{f,d}$ and consequent resistance to fire rating for each floor of the considered building are summarized in **Table 30**.

Table 30 – Resistance to fire evaluation

		S.2 - Resistance to fire															
Floor	**Room/occupancy**	***Required performance level (based on the higher R_{life} for the floor)***	**Fire load density q_f [MJ/m2]** *ref. To 80% fractile*	δ_{q1}	δ_{q2}	δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}	**Design fire load $q_{f,d}$ [MJ/m2]**	**Minimum resistance to fire rating for compliant solution**
Basem.	Storage, laundry, offices	III	3000	1,60	1,00		0,80			0,48		0,90	0,90	0,85	0,81	1028	90
1	Offices Patient rooms Storage Common spaces	III	570	1,60	1,00		0,80					0,90	0,90	0,85	0,81	407	30
2	Offices Auditorium Cafeteria Common spaces	III	570	1,60	1,00		0,80					0,90	0,90	0,85	0,81	407	30
3	Treatment rooms Offices	III	570	1,60	1,00		0,80					0,90	0,90	0,85	0,81	407	30
4	Patient rooms Laboratories Physical therapy Imaging rooms	III	350	1,60	1,00		0,80					0,90	0,90	0,85	0,81	250	15 (#)
5	Surgery Patient rooms	III	350	1,60	1,00		0,80					0,90	0,90	0,85	0,81	250	15 (#)

		S.2 - Resistance to fire															
Floor	Room/occupancy	*Required performance level (based on the higher R_{life} for the floor)*	Fire load density q_f [MJ/m2] *ref. To 80% fractile*	δ_{q1}	δ_{q2}	δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}	Design fire load $q_{f,d}$ [MJ/m2]	Minimum resistance to fire rating for compliant solution
6	Neonatology	III	350	1,60	1,00	0,90						0,90	0,90	0,85	0,81	281	15 (#)
	Patient rooms																
7	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
8	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
9	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
10	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
11	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
12	Patient rooms	III	350	1,60	1,00	0,90						0,90	0,90	0,90	0,80	281	15 (#)
13	Medical offices	III	570	1,60	1,00	0,90				0,48		0,90	0,90	0,90	0,80	230	15
14	Medical offices	III	570	1,60	1,00	0,90				0,48		0,90	0,90	0,90	0,80	230	15
15	Medical offices	III	570	1,60	1,00	0,90				0,48		0,90	0,90	0,90	0,80	230	15
16	Medical offices	III	570	1,60	1,00	0,90				0,48		0,90	0,90	0,90	0,80	230	15

NOTE

(#): Although, according to calculation results, the minimum fire resistance rating for the floors between the 4th and the 12th is equal to 15 minutes, structures will be characterized by resistance to fire not less than 30 minutes, considering the minimum resistance rating for the filters as representative for the entire floor.

Minimum fire resistance ratings are calculated according to the following hypotheses:

- if multiple occupancies are present on the same floor, the higher value of fire load density (based on literature references) has been considered as representative for the entire floor;
- the required performance level for compliant solution in resistance to fire evaluation is based on the higher R_{life} for each floor (ref. to Chapter 4 for details);
- the δn2 coefficient has been considered only for the first five floors, assuming that the upper floors cannot be reached by the hose stream jet. For the upper floors (starting from the 6^{th} one), only indoor fire hydrants are considered (δn1 coefficient);
- the δn5 coefficient has been considered only for the basement level and for the upper floors (Office level 13^{th} to 16^{th}), where in addition to the indoor and outdoor fire hydrants will be implemented also automatic sprinkler systems;
- common firefighting measures considered for all floors are the following:
  - firefighting safety management system (δ_{n7} coefficient);
  - heat and smoke control system (δ_{n8} coefficient);
  - detection and alarm system (δ_{n9} coefficient);
  - firefighting operativity measures (δ_{n10} coefficient).
- although, according to calculation results, the minimum fire resistance rating for the floors between the 4^{th} and the 12^{th} is equal to 15 minutes, structures will be characterized by resistance to fire not less than 30 minutes, considering the minimum resistance rating for the filters as representative for the entire floor.

8. Compartmentation

According to Italian current fire regulation for health-care facilities (D.M. 19/03/2015), areas could be classified as:

- **Type A**: Specific risk activities (technical plants, car parking, etc.);
- **Type B**: Specific risk area, accessible only to staff laboratories, storages, laundries, etc.);
- **Type C:** Out-patient areas (ambulatories, specialized centers, diagnostic centers, counselling rooms, etc.);
- **Type D1**: Inpatient areas, same-day surgery;
- **Type D2**: Specialized medical cares (ER, Intensive care units, operating suites, neonatology, etc.);
- **Type E**: Areas related to utilities and other auxiliary services (administrative offices, conference areas, food service areas, common spaces, etc.);
- **Type F:** Areas with high-technology machines, x-ray, MRI scan equipment.

Healthcare-facilities has to be designed to contain and limit fire propagation and the followings prescriptions have to be implemented, according to [19].

- Type C areas have to be designed with a maximum surface of 1500 m^2;
- Type E areas have to be divided in compartments according to occupancies and have to be designed in compliance with specific fire prescriptions, if subjected (technical plants, assembly areas with large surface, etc.);
- Type D compartments have to be smaller than 1000 m^2;
- Type D2 and E compartments (limited to assembly rooms, canteens, schools, etc.) could communicate with other compartments only through smoke proof filters or open spaces;
- Type C, D1 (inpatient rooms) and E (offices) could communicate with other compartments through fire resistance doors, which characteristics has to be defined according to specific fire load of adjacent compartments and separation structures;
- Type B compartments has to be compliant with specific prescriptions, according to compartment surface and fire load.
- Type F areas could not be placed more than two level above ground and a have to be separated from D type compartments through filters.

As Type B compartments are concerned, [19] differentiate among areas with different surface. In particular, if the total area of the B compartment is larger than 500 m^2: compartments could not be placed at the same floor of areas C, D1, D2 and F, separating structures have to be 90' fire resistance rated, fire detection system has to be present and, if the fire load value exceeds 1062 MJ/m^2, an automatic fire extinguishing system has to be installed in the compartment.

The definition of fire compartment, according to Italian Fire Code [12] is: a delimitated part of a building, in which, due to structural configurations and specific building materials, the fire resistance is granted for a certain interval of time.

Basing on these assumptions, the hospital structure has been divided in compartments, according to **Table 31**.

Table 31: Compartment configuration in the building

Compartment	Floor	Occupancy	Classification	Surface [m^2]
B-01	Basement	Storage	B	2794
L1-01	1	Back of house areas, storage	B	427.3
L1-02	1	Patient rooms, counselling rooms	D1	480.8
L1-03	1	Storage	B	125.6
L1-04	1	Emergency room	D2	281.2
L1-05	1	Admission hall	E	1026.7
L2-01	2	Auditorium	E	403.02
L2-02	2	Conference room	E	260.5
L2-03	2	Storage	B	90
L2-04	2	Administrative offices	E	209.4
L2-05	2	Cafeteria hall, kitchen, administrative offices	E	1236.8
L3-01	3	Out-patient clinic	C	530.4
L3-02	3	Out-patient clinic	C	530.4
L3-03	3	Storage	B	125.6
L3-04	3	Storage	B	90
L3-05	3	Out-patient clinic	C	530.4
L3-06	3	Out-patient clinic	C	530.4
L4-01	4	Imaging ambulatories	F, C	530.4
L4-02	4	Laboratories	B	530.4
L4-03	4	Storage	B	125.6
L4-04	4	Storage	B	90
L4-05	4	Same-day surgery	D1	530.4
L4-06	4	Physical therapy	C	530.4
L5-01	5	Operating suites	D2	547.5
L5-02	5	Operating suites		547.5
L5-03	5	Storage	B	125.6
L5-04	5	Storage	B	90
L5-05	5	Operating suites	D2	255.9
L5-06	5	Inpatient rooms	D1	274.5
L5-07	5	Inpatient rooms	D1	274.5
L5-08	5	Operating suites	D2	255.9
L6-01	6	Birthing unit, operating suites	D2	530.4
L6-02	6	Neonatology	D2	530.4
L6-03	6	Storage	B	125.6
L6-04	6	Storage	B	90
L6-05	6	Birthing unit, patient rooms	D1	530.4
L6-06	6	Patient care rooms	D1	530.4
L7-01 [*]	7	Patient care rooms	D1	530.4
L7-02 [*]	7	Patient care rooms	D1	530.4
L7-03 [*]	7	Storage	B	125.6
L7-04 [*]	7	Storage	B	90
L7-05 [*]	7	Patient care rooms	D1	530.4
L7-06 [*]	7	Patient care rooms	D1	530.4
L13-01 [**]	13	Medical offices	E	530.4
L13-02 [**]	13	Medical offices	E	530.4
L13-03 [**]	13	Storage	B	125.6
L13-04 [**]	13	Storage	B	90
L13-05 [**]	13	Medical offices	E	530.4
L13-06 [**]	13	Medical offices	E	530.4

[*] Since floors from 8th to 12th have the same compartment configuration and occupancy of 7th floor, they have been omitted from **Table 31**.

[**] Since floors from 13th to 16th have the same compartment configuration and occupancy of 13th floor, they have been omitted in **Table 31**.

In **Table 31,** when different occupancies are found within the same compartment, the most relevant (in terms both of fire safety and surface occupied) is indicated.

Fire resistance of compartments has been defined accordingly to chapter 7 of this report. In FLAME evaluation, although, a different classification of fire resistance structures has been chosen:

- Fire Resistance greater than 60, for Basement level;
- Fire Resistance equal to 30 for compartments at floors 1st to 5th;
- Fire Resistance greater than 30 for compartments at floors above 5th.

This choice has been adopted as to obtain an adequate score in the CC index (Compartment configuration), which depend strongly from compartment level, as in **Figure 6** and from fire resistance grade of structures, as in **Figure 7**. The Compartment Configuration is higher as the fire protection level is lower.

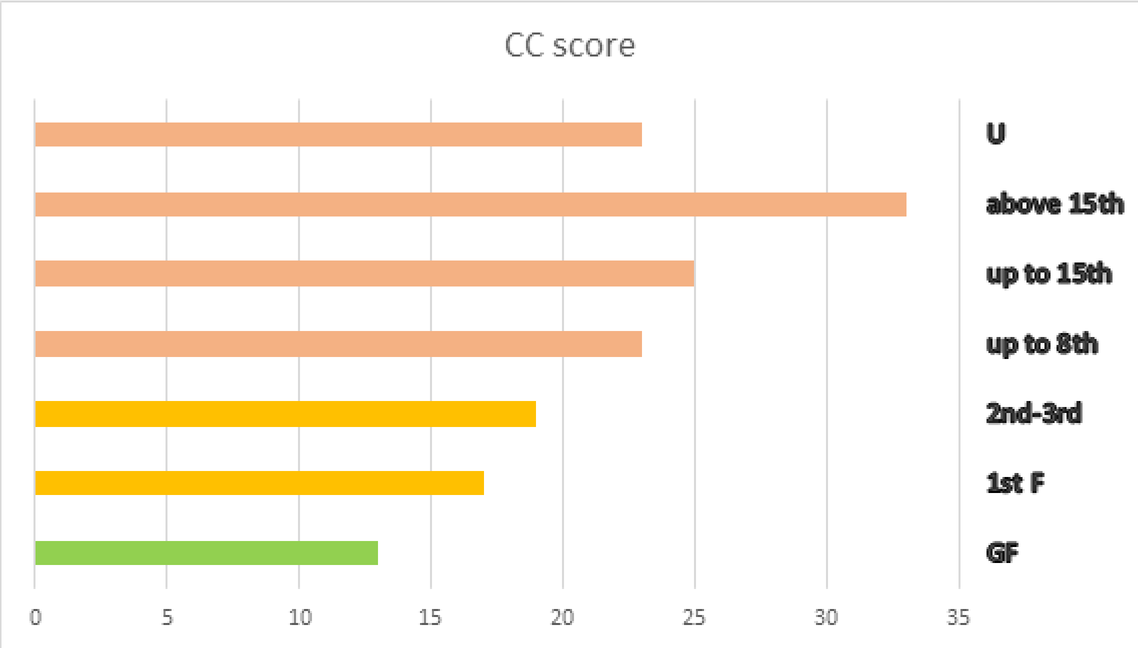


Figure 6 – CC index variation with respect to floor where the compartment is located, with all the other parameters fixed.

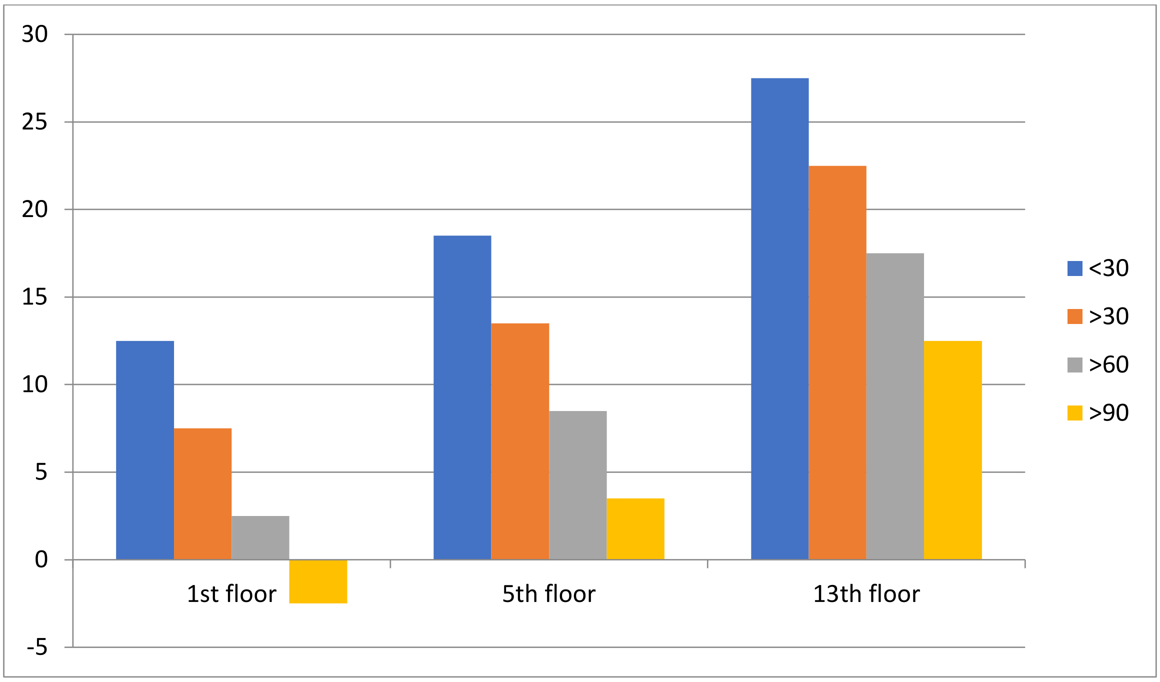


Figure 7 – Fire resistance contribution to CC index, for compartment at different levels from ground.

In **Annex B** a representation of the different compartments is shown.

9. Occupants and Fire brigade safety

In order to evaluate occupants' safety an RSET-ASET study has been performed. A computational study to evaluate different conditions has been done both for evacuation and for fire dynamics analysis. From the results of the simulation two times have been estimated:

- Available Safe Egress Time (ASET);
- Required Safe Egress Time (RSET);

Safety conditions for occupants are considered to be guaranteed if:

$$ASET > RSET$$

Meaning that is possible to reach a place of relative safety before untenable conditions develop in the building. The performance criteria to establish the tenability status are the ones required from the Italian Fire Code and are evaluated at a height of 2 m from the floor level.

The performance criteria to establish the level of tenability are:

Table 32 - Performance criteria

Parameter	Tenability for occupants	Tenability for Fire Brigade
Temperature	< 60 °C	< 80 °C
Visibility	> 10 m	> 5 m

9.1 ASET Analysis

The conditions in case of fire are examined using the software FDS (Fire Dynamic Simulator), which is a CFD model of fire-drive fluid flow that solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow.

In **Figure 8** the 3-D model of the Building is shown. A grid size of 20 cm has been used for the simulations.

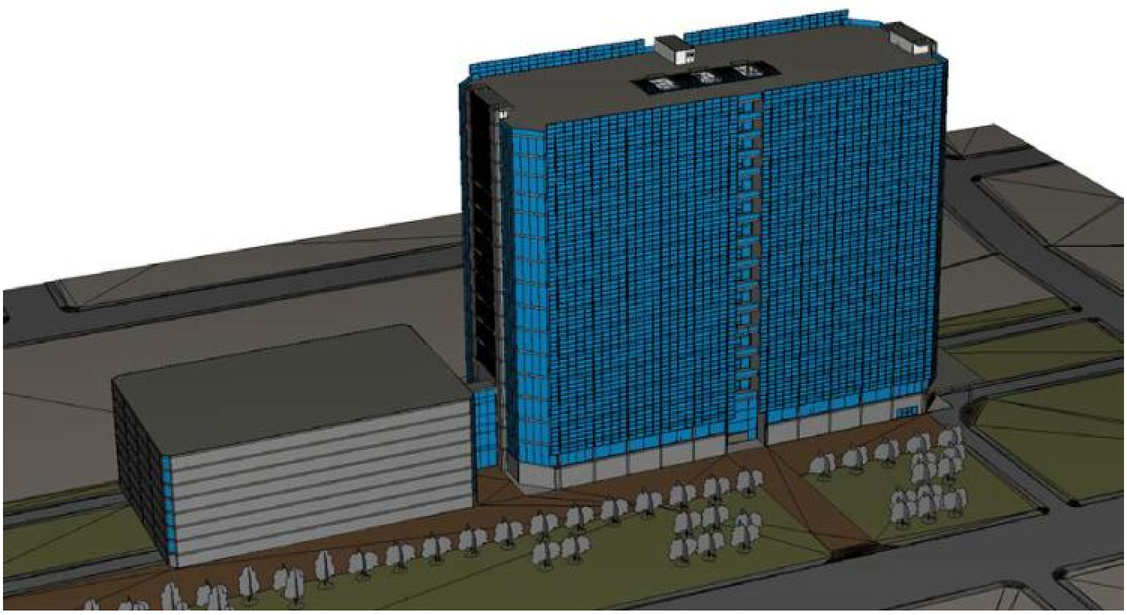


Figure 8 - FDS Model

9.1.1 Fire Safety concept

The building is equipped with a general fire detection system and a distributed push button system. The detection automatically activates the evacuation alarm and the smoke and heat control system.

The building is equipped with a standard water sprinkler installation in the Basement, in the Offices on floors 13th to 16th and in the kitchen on the first floor.

A natural smoke and heat control system is provided on the roof of the atrium, so that the smoke can be extracted vertically and a safe evacuation can be performed in case of fire on the lower floors (Ground and 1st floor). The openings on the roof will automatically open in case the detection system turns on.

The natural smoke and heat control system intervenes also to protect from a fire on the upper floors, in those cases it will act as an oxygen provider while dedicated natural smoke extraction shafts will extract the smoke. In **Figure 9** an example of the extraction of smoke from the lateral shaft and air inlet from the opening on the roof is shown.

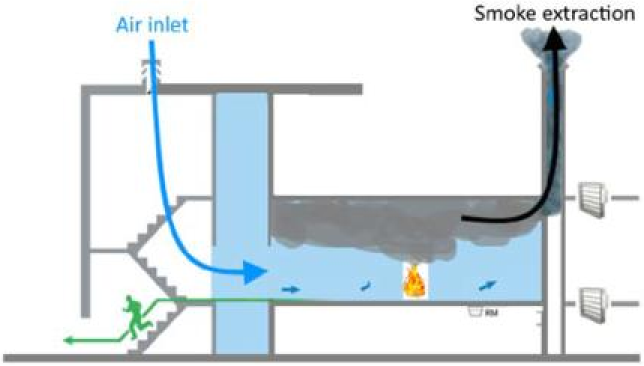


Figure 9 - Lateral extraction shaft

For each compartment two extraction shafts will be installed. The strategy for one of the compartment of the 13th floor is shown in **Figure 10** as example. Thanks to the inlet of fresh air from the atrium it's guaranteed that there is a smoke free entrance for a safe fire brigade intervention coming from the atrium itself.

Figure 10 - Fire safety concept on floor 13th

9.1.2 Fire Brigade intervention

The alarm of the fire brigade is initially done by the health-care premise manager himself or by an authorized person. Given the complexity of the building, two access paths for the fire brigade are available.

Fire Brigade can reach every part of the building through two separate rescue lifts and three staircases. The main access to the building are located on the ground floor and are shown in **Figure 11**.

Figure 11 – Fire Brigade access

On the upper floors the fire brigade can enter in each compartment from the atrium or from the filter of the rescue lift. Since in the building there is availability of water protection system (hoses) they can use those instruments to extinguish the fire; due to the distance of around 15 m which is reachable with a water hose, they can start the intervention from a distance of around 15 m from the fire.

In **Figure 12** an example of the fire brigade accesses to an incident compartment on the 5th floor is shown. Every circle is centred on one of the access door to the compartments, and has a radius of 15 m, which is the distance from which the intervention can be performed. As can be see, in the highlighted compartment the fire brigade can enter from the filter of the rescue lift and from the atrium.

Based on those consideration the tenability criteria need to be satisfied so as to let the fire brigade intervention to be performed safely: meaning that the entrance to the compartments need to be free of smoke and at low temperature.

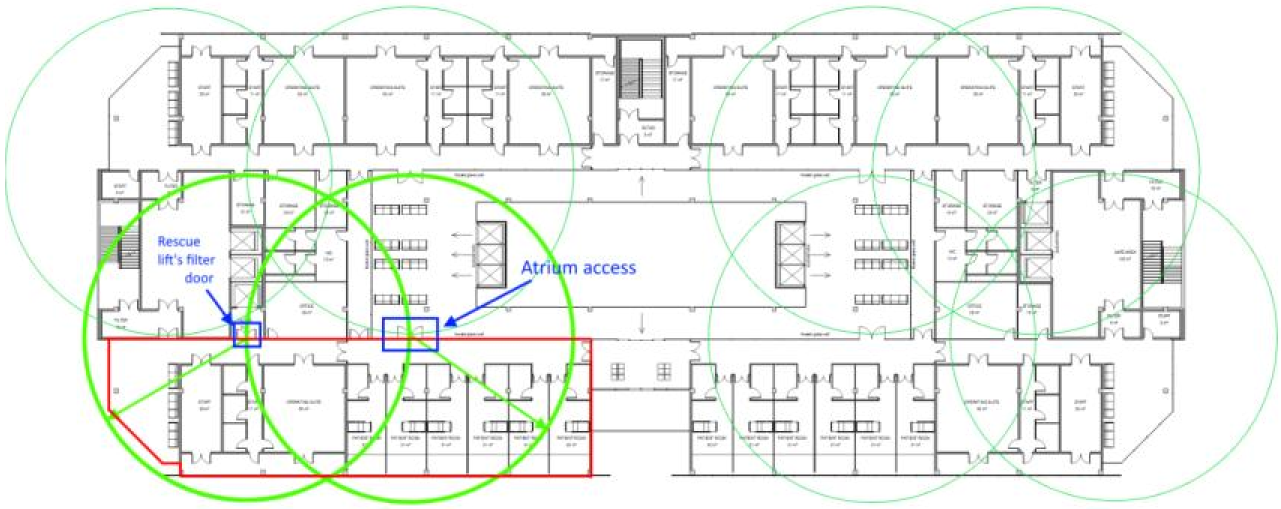


Figure 12 – Fire brigade access on the 5th floor

In **Figure 13** an example of the fire brigade accesses to an incident compartment on the 15th floor is shown. Every circle is centred on one of the access door of the compartments, and has a radius of 15 m, which is the distance from which the intervention can be performed. As can be see, in the compartment highlighted the fire brigade can enter from the filter of the rescue lift and from the atrium.

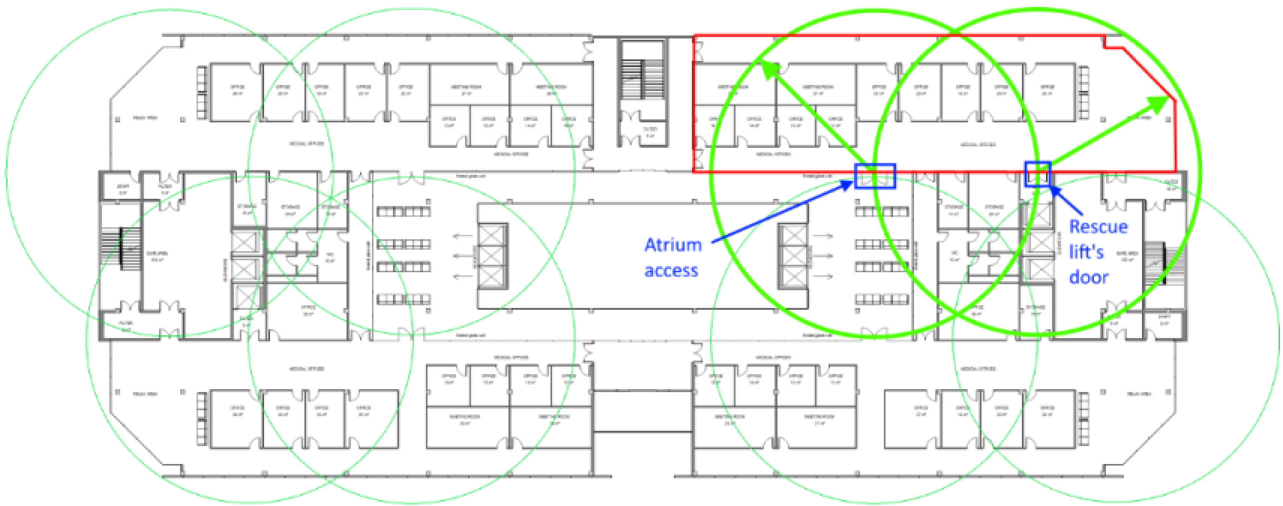


Figure 13 – Fire brigade access on the 12-16th floor

9.1.3 Design Fire

Based on a Fire Risk Assessment, different types of fire location and dimension have been identified:

- A fire in a patient room
- A fire in the hall (atrium)
- A fire in the cafeteria
- A fire in an office
- A fire in the laundry (Basement level)
- A fire in a parking slot

A literature study has been done to identify the Heat Release Rate curve for the fires under analysis; for those fires for which a specific fire curve is not available a t-squared grow rate has been assumed: this curve is expressed as:

$$\dot{Q} = \alpha \cdot t^2$$

where α is a growth factor (kW/s^2) and t is the time from established ignition (s).

It has been considered that due to the presence of a sprinkler system the fire continues to grow until the sprinkler activation, after which a steady state condition is reached.

The activation time has been calculated considering the following physical aspects:

- Cooling effect due to air entrainment: as the smoke plume rises from the fire, it entrains air from the surroundings which causes the smoke plume to cool down.
- Ceiling height: the higher the ceiling, the lower the temperature of the smoke which reaches the sprinklers. The hotter the smoke the more rapidly the sprinkler will activate.

The time to sprinkler operation depends on:

- Fire growth rate
- Sprinkler location
- Thermal sensitivity

Thermal sensitivity of a sprinkler determines how fast it will heat up once immersed in a hot gas layer such as the ceiling jet plume from a fire. The thermal sensitivity is characterised by its Response Time Index (RTI). A smaller RTI value indicates a more thermally sensitive element.

The computer program DETACT-T2 (developed by NIST) has been used to predict the sprinkler response time and the corresponding fire size at the time it activates. The software calculates the response time by combining the fire growth, the sprinkler location and the sprinkler sensitivity.

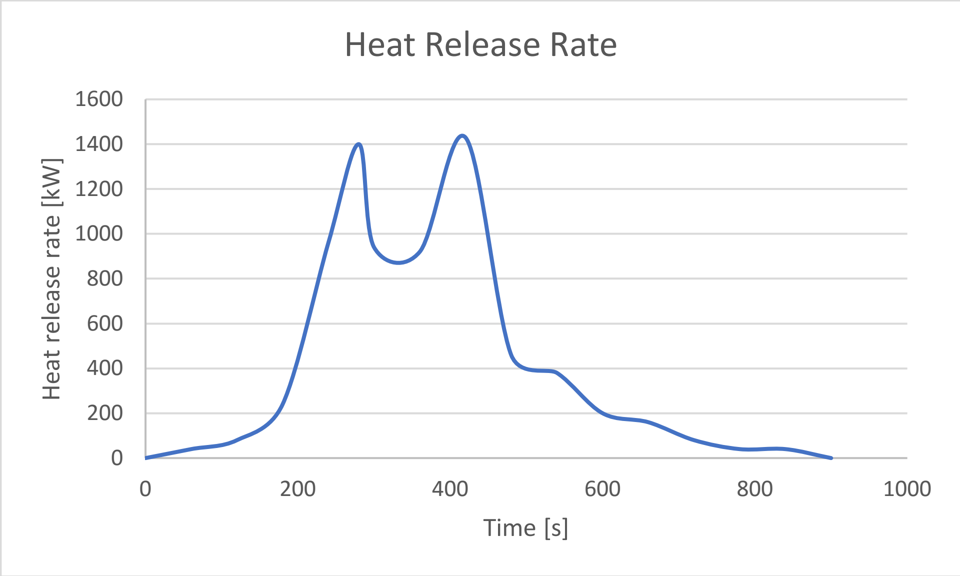
The parameters selected for the sprinkler system assumed to be installed in the health-care premise are:

Table 33 - Sprinklers system's characteristics

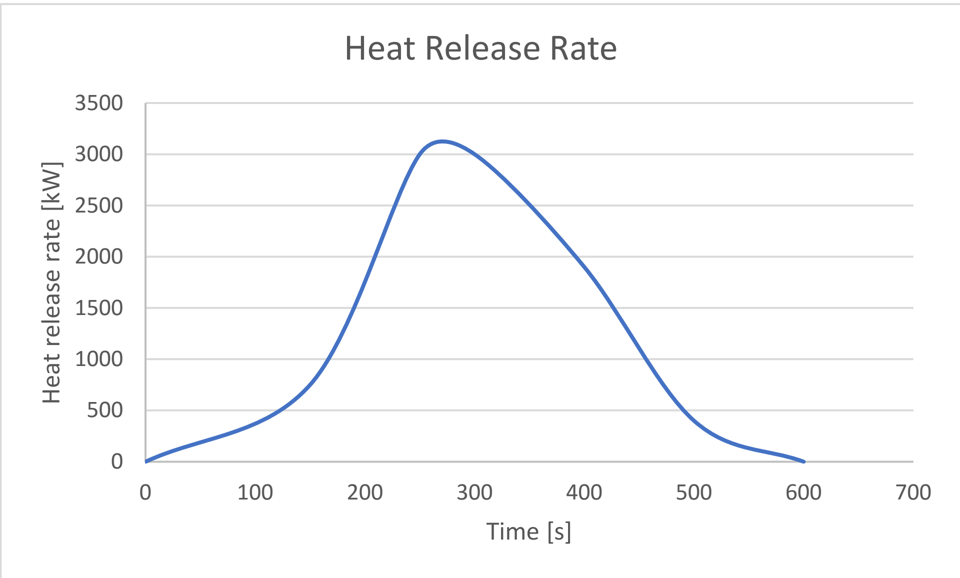
Sprinkler Type	Quick response sprinkler (RTI = 50)
Activation temperature	57 °C (Orange)
Ceiling height	6-4-5 m
Sprinkler spacing	1 m

The method utilizes the basic correlations for jet temperatures and velocities, using Alpert's correlations. The fire may grow before activation of a sprinkler head at which point the fire would become steady state (i.e. the sprinklers suppress further fire growth).

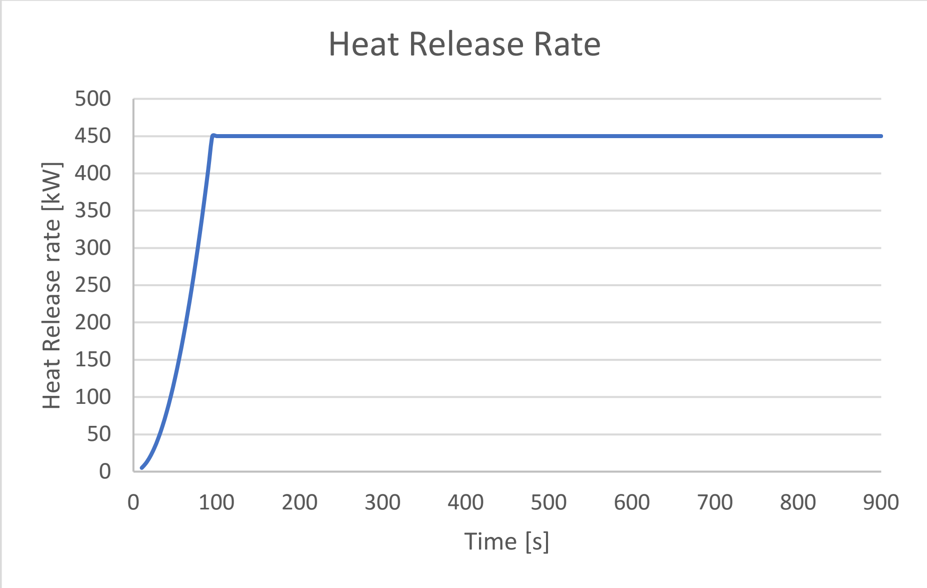
Fire in a patient room

Heat release rate – Fire in a patient room	
To represent the fire in the patient room a fire of a bed has been considered. Based on [20] the fire is characterized by the curve in the Figure beside. The growing rate has been selected considering a fire retarded treated material bed. The estimate activation time of the detection system has been done with a CFD simulation.	

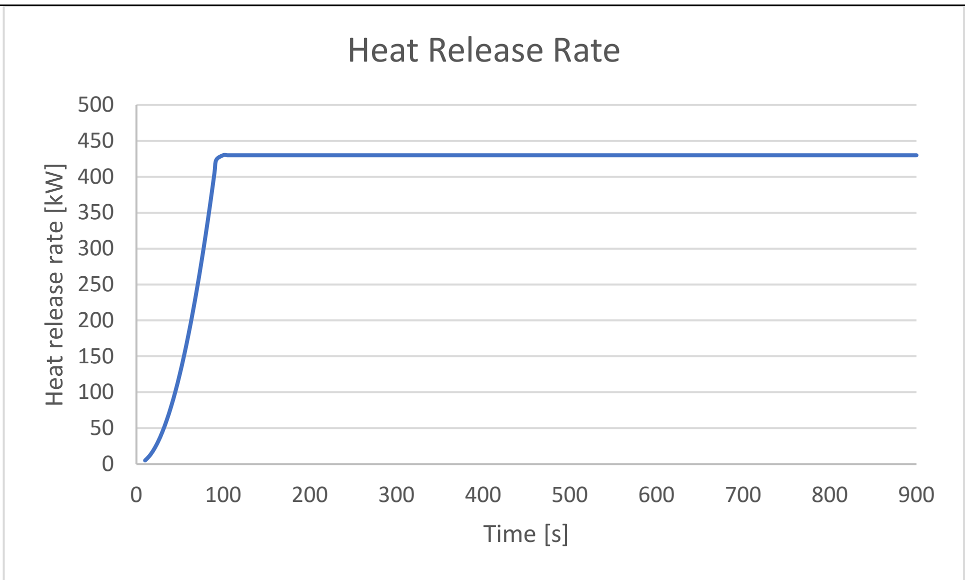
Fire in the hall

Heat release rate – Fire in the atrium	
As a characteristic fire for the atrium a fire of sofa on the ground floor has been assumed. Based on [20] the fire is characterized by the Heat release curve shown in the Figure beside. The estimate activation time has been estimated with a CFD simulation. For the fire protection of the atrium a natural ventilation system is installed. The dimensioning of the ventilation system has been done in compliance with the requirements of the UNI9494.	

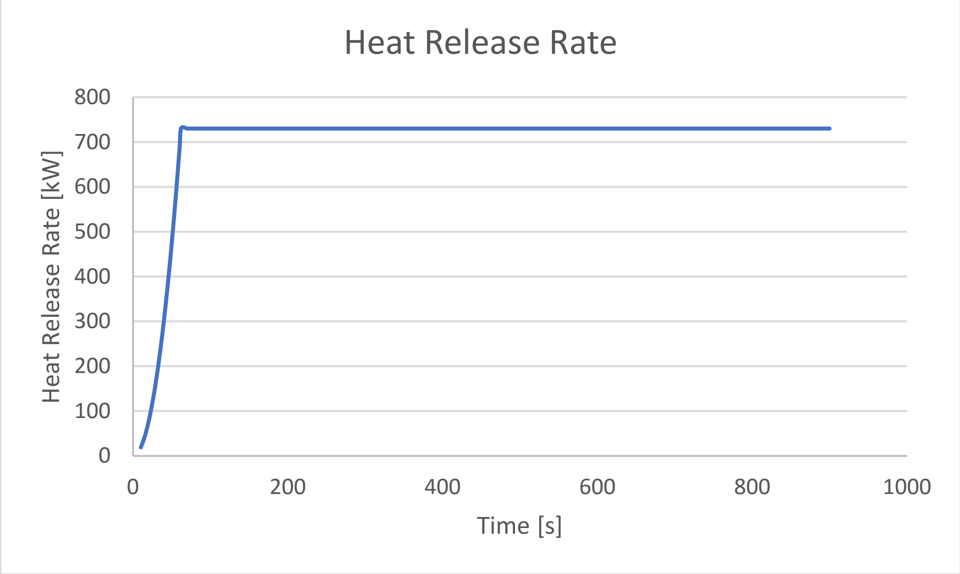
Fire in the kitchen

Heat release rate – Fire in the kitchen	
A fire of two adjacent trash bins is supposed to start in the kitchen located on the first floor. Based on [7] the fire is characterized by a growth factor of 0.05 kW/s^2, corresponding to a fast-growing rate. Since in the room there is a sprinkler system, the fire curve will reach a steady state at the moment thesprinkler system turns on. The estimate activation time from DETACT-T2 is 95 seconds, at which the fire reaches a Heat Release Rate of 450 kW.	

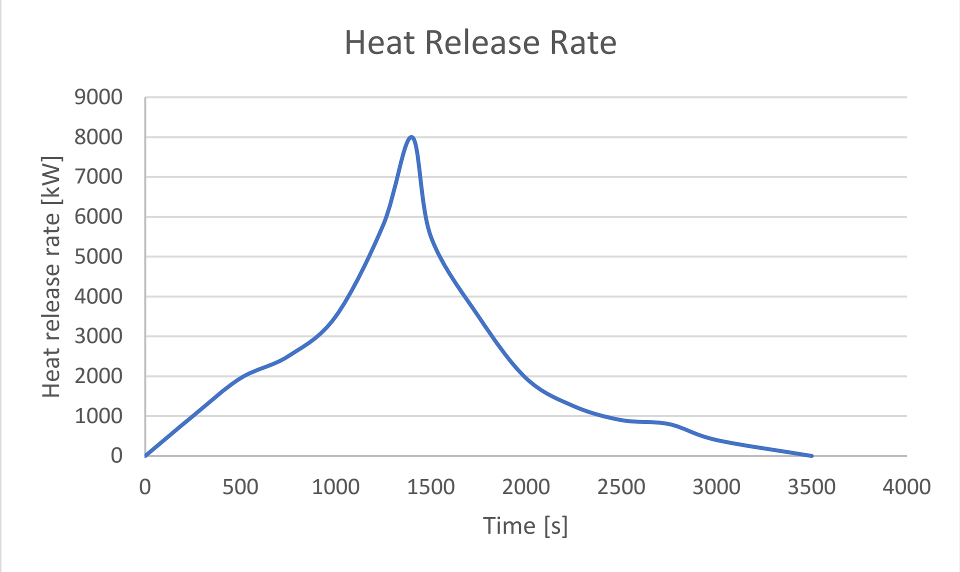
A fire in an office

Heat release rate – Fire in an office	
Based on [7] a fire in an office is characterized by a fast growth rate of 0.047 kW/s^2. Since in the room there is a sprinkler system, the fire curve will reach a steady state value at the moment the protection system turns on. The estimate activation time from DETACT-T2 is 95 seconds, at which the fire reaches a Heat Release Rate of 430 kW.	

A fire in the laundry (basement)

Heat release rate – Fire in the basement	
Based on [7] a fire in a storage room is characterized by an ultra-fast growth factor of 0.19 kW/s[2]. Since in the room there is a sprinkler system, the fire curve will reach a steady state value at the moment the protection system turns on. The estimate activation time from DETACT-T2 is 60 seconds, at which the fire reaches a Heat Release Rate of 730 kW.	

Fire in the car parking

Heat release rate – Fire in the car parking	
Based on [21] the heat release rate of a car fire on fire is shown in the Figure beside. In the car parking an HVAC system avoids the smoke propagation to the adjacent Hospital.	

For the analysis the values for CO yield and Soot yield have been taken from [22], which suggests yield values for different types of occupancies. The values are:

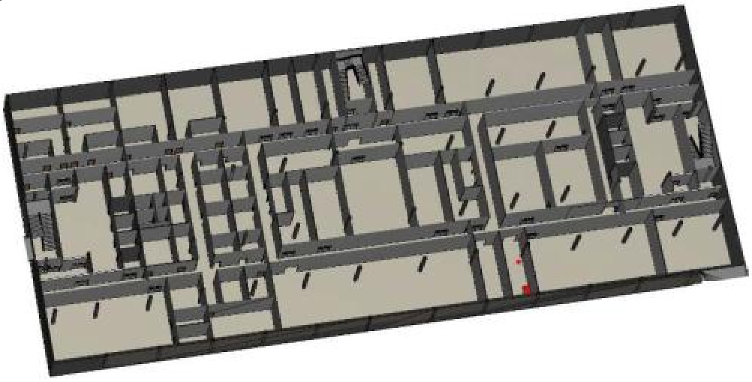
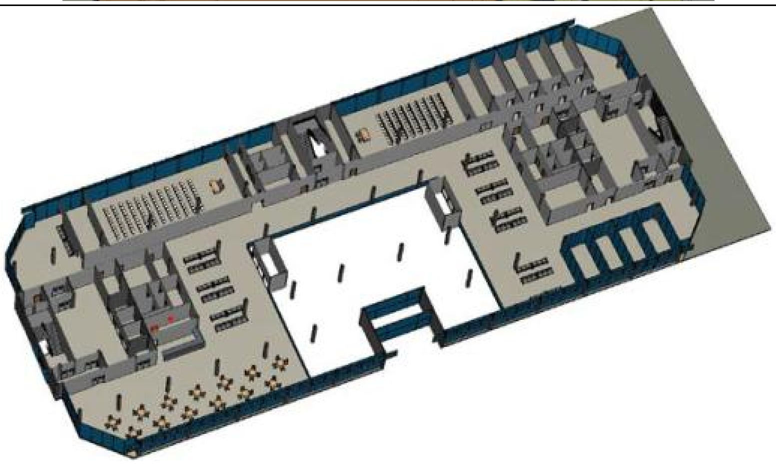
- CO_YIELD=0.01,
- SOOT_YIELD=0.03

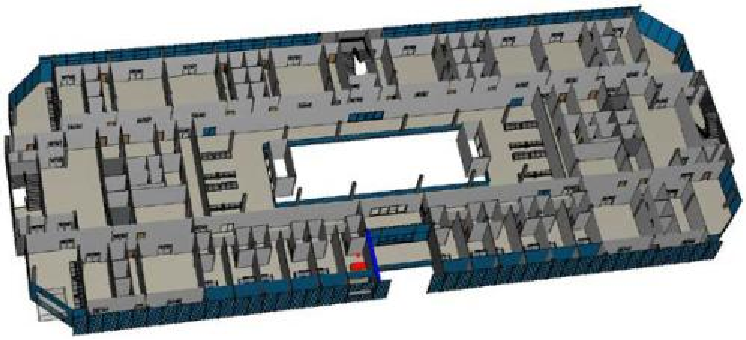
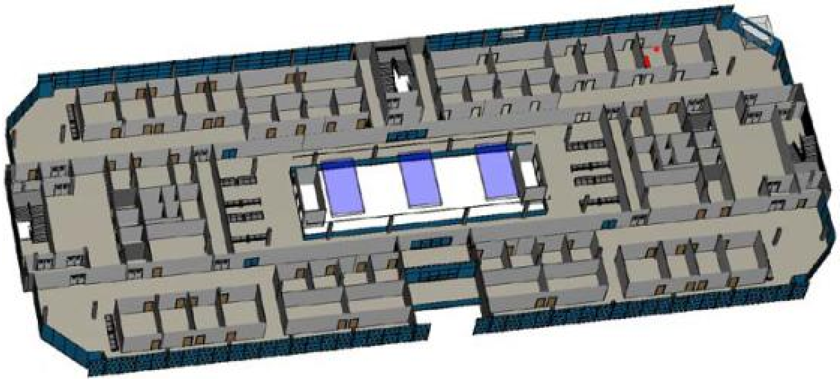
It should be noted that those fire curves are taken from a literature study and don't take into account the strict requirements given for fire reaction to fire of the allowed materials.

9.1.4 Scenarios

In the **Table 34** a summary of the run scenarios is reported:

Table 34 – Fire Scenarios

Fire Scenario	Floor Level	Fire Location	Floor representation and fire position (in red)
1	Basement	Laundry	
2	Ground	Hall	
3	First	Kitchen	

4	Fifth	Patient room	
5	Fifteenth	Office	

Each scenario has been run for 15 minutes, which it's the time after which the fire brigade intervenes. It's assumed that only one fire per time can start.

9.1.5 Results

Output files for temperature and visibility have been set-up at a level of 2 m.

Devices for the estimation of the detection system activation time have been distributed at roof level.

In **Table 35** a summary of the results of the simulations is shown:

Table 35 - Summary of Results (FDS)

Scenario	Untannable conditions for occupants	Untannable conditions for fire brigade	Detection Time[1]
1	300 s	900 s	53 s
2	900 s	900 s	165 s
3	900 s	900 s	78 s
4	900 s	900 s	53 s
5	300 s	900 s	53 s

In **Annex C** the results are shown in details.

[1] Given the detection times estimated with the CFD analysis the assumed fire curves can be considered correct: meaning that the plateau of the curve after the activation of the protection system is realistic.

9.2 RSET Analysis

Pathfinder is the egress model applied to simulate the evacuation, the software has been developed by Thunderhead Engineering. It is a continuous model and represents the movement of the agents using a system of coordinates. The movement of the agents has been simulated using the agent-based model, through which agents move along their path using a steering system that allows each agent to interact with the environment and the other agents.

Escape time (RSET) in safe conditions depends on four different "times", influenced by occupants physical and behavioural characteristics. The four times are:

- Detection Time: the time from the beginning of ignition to its detection by a manual or automatic system. It may vary according to the scenario, the fire detection system and the ability occupants have to detect the fire.
- Alarm Time: the time the detection to triggering a general alarm
- Pre-movement Time: the time from the detection to the moment the first occupant starts moving
- Travel Time: the time occupants take to move from where they are to a safer place.

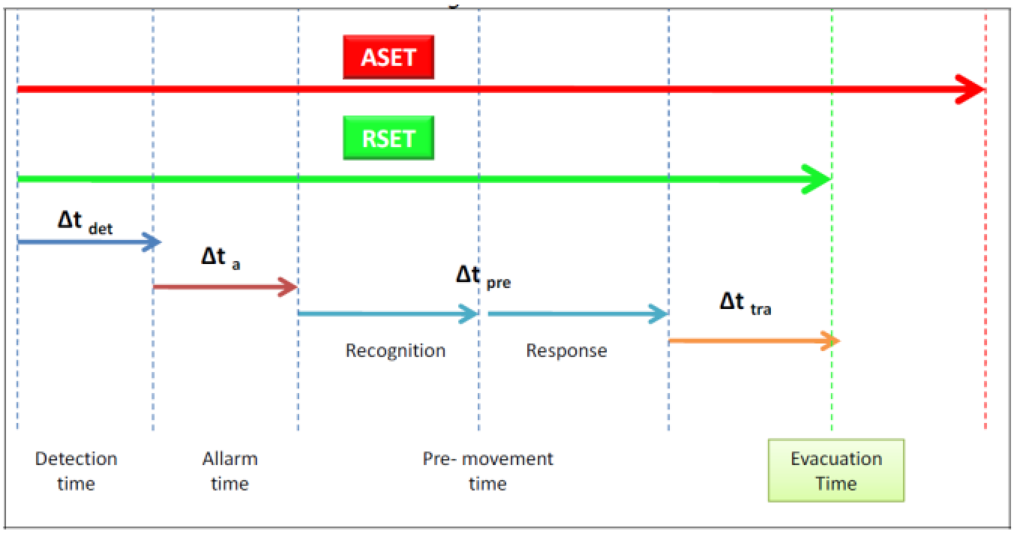


Figure 14 – Time table for evacuation

The *travel speed* for:

- people with normal locomotion capacity is assumed to be represented by a normal distribution with an average unimpeded walking speed of 1.25 m/s and a standard deviation of 0.32 m/s;
- people with locomotion disabilities is assumed to be represented by a normal distribution with an average unimpeded walking speed of 0.8 m/s and a standard deviation of 0.32 m/s;
- assisted ambulant people is assumed to be represented by a normal distribution with an average unimpeded walking speed of 0.78 m/s and a standard deviation of 0.34 m/s;
- assisted people with manual wheelchair is assumed to be represented by a normal distribution with an average unimpeded walking speed of 1.30 m/s and a standard deviation of 0.94 m/s.

Table 36 - Travel speed

Type of people	Mean	Stand. Dev.	Range
No locomotion disabilities	1.25	0.32	0.82-1.77
With locomotion disabilities	0.8	0.32	0.24-1.68
Assisted ambulant	0.78	0.34	0.21-1.40
Assisted manual wheelchair	1.30	0.94	0.84-1.98

Walking speed is then automatically adjusted by the models during the simulation in relation to people density, properties of the elements of the geometry (i.e., horizontal or vertical egress components), etc. The data has been taken from [23]. The choice of using a normal distribution is due to the necessity of taking into account the variability of the population.
Stairs are represented in Pathfinder through straight-run of steps. The model requires the input data about riser, tread and width. In Pathfinder, the specified tread rise and run are the factors considered in the calculation, i.e., the simulation is not dependent on the geometric slope of the stairs.
In a room where the density is less than 0.55 pers/m^2 the base speed is expressed by the following equation:

$$v(D) = v_{max} * \frac{85 * k}{1.19}$$

k depends on the type of terrain being traversed. Stairways denote areas where the maximum occupant speed is controlled by an alternate specific calculation; it depends on the slope of the stairway as follows:

Table 37 - Speed on stairway

Stair Riser (inches)	Stair Tread (inches)	k
7.5	10.0	1.00
7.0	11.0	1.08
6.5	12.0	1.16
6.5	13.0	1.23

There are different cues which can alert the occupants in case of emergency:

- Cues from the fire environment (or fire cues)
- Cues from the building
- Cues from people in the building

The presence of other people will influence behaviour and decision making (response is affected by others). In a health-care premise with a distributed detection system, the building cues may be a first cue to the staff, that will trigger the initiation of other cues such as alerting others. For in-patient persons, the pre-movement time can be assumed to be equal to that of the staff which will drive the evacuation.

A semi-quantitative evaluation of pre-movement time was obtained from the risk assessment performed by FLAME, which gives different pre-movement time classes as for different occupancies (see chapter 3). As to perform a quantitative analysis on the time required to escape by occupants of the different compartments of the present case a more quantitative methodology is due.
SPFE handbook reports how pre-movement time (here defined as delay to travel time) has been recently discussed and different estimation method do exist, though literature is still scarce in this field of the fire safety engineering. Estimates could derive from actual evacuation drills, from fire victim's interviews and from simulations. SPFE handbook reported how the warning cues and alarms marked significantly variations in the delay time to start evacuation and that :" messages delivered through a voice communication system or directly by staff seem to be the signals that are taken most seriously by occupants as indicating a requirement to promptly leave the area".

The *pre-movement time* in this study has been defined for the specific scenario, based on [24]:

Table 38 - Pre-movement time

Type of people	Pre-evac time
Staff	10 s after the alarm
In-patient persons	Depend on staff
People in the office	30 s after alarm
People at the cafeteria	60 s after the alarm

After the fire has been detected, the staff spends some time interpreting the situation. As the staff is trained to respond to fire alarms, the reaction time is considered to be very short only 10 s. For the other locations, the reaction time is longer, approximately 60 s in the cafeteria and entrance hall and 30 s in the offices and medical care units.

The presence of an advanced alertment system providing live directives using voice live communication directives in conjunction with well-trained, uniformed staff that can be seen and heard by all occupants in the space (as reported also by BS 7974-6:2004) allow to define the pre-movement time values presented in the table above.

The occupancies of the building have been determined based on the Italian Safety Code DM 03/08/2015 and NFPA 101 “Life safety code”, 2015 edition. In the following table are summarized the occupancies identified in the building and their occupant load factors.

Table 39 - Occupants load

Floor	Room/Occupancy	Occupant load factor [p/m^2]	Code Ref.
Basem.	Storage, laundry	0,02	[a]
	offices	0,1	[f]
1	offices	0,4	[e]
	patient rooms	24 pp	[b]
	storage	0,02	[a]
	common spaces	0,7	[c]
2	offices	0,4	[e]
	auditorium	214 pp	[l]
	cafeteria	0,7	[d]
	common spaces	0,7	[c]
3	treatment rooms	0,05	[g]
	offices	0,1	[f]
4	patient rooms	48 pp	[b]
	laboratories	0,11	[h]
	physical therapy	0,72	[i]
	imaging rooms	0,11	[h]
5	surgery	0,11	[h]
	patient rooms	36 pp	[b]
	Common spaces	0,7	[c]
	Storage	0,02	[a]
	Sfatt rooms	0,4	[e]
6	neonatology	48 pp	[b]

Floor	Room/Occupancy	Occupant load factor [p/m²]	Code Ref.
	patient rooms	84 pp	[b]
7	patient rooms	120 pp	[b]
8	patient rooms	120 pp	[b]
9	patient rooms	120 pp	[b]
10	patient rooms	120 pp	[b]
11	patient rooms	120 pp	[b]
12	patient rooms	120 pp	[b]
13	medical offices	0,1	[f]
14	medical offices	0,1	[f]
15	medical offices	0,1	[f]
16	medical offices	0,1	[f]

NOTE:
[a] 0.02 p/m² storage – ref. NFPA 101, Table 7.3.1.2, storage use, "in other than storage and mercantile occupancies";
[b] patient rooms – ref. 53talian DM 05/08/2015, Table S.4-6, patient rooms, to be considered n.1 patient and n.2 accompanists;
[c] 0.7 p/m² common spaces – ref. to NFPA 101, Table 7.3.1.2, assembly use, "less concentrated use, without fixed seating";
[d] 0.7 p/m² caffetteria – ref. 53talian DM 05/08/2015, Table S.4-6, restaurant area;
[e] 0.4 p/m² – ref. 53talian DM 05/08/2015, Table S.4-6, 53talia officies;
[f] 0.1 p/m² – ref. 53talian DM 05/08/2015, Table S.4-6, private officies;
[g] 0.05 p/m² treatment room/surgery – ref. NFPA 101, Table 7.3.1.2, health care use, "impatient treatment department";
[h] 0.11 p/m² laboratories – ref. NFPA 101, Table 7.3.1.2, health care use, "ambulatory health care";
[i] 0.72 p/m² – ref. to NFPA 101, Table 7.3.1.2, assembly use, "exercise room without equipment";
[l] n° of seats – ref. 53talian DM 05/08/2015, Table S.4-6, meeting room.

Assisted patients

The number of staff available in case of emergency has been estimated based on Italian Decree D.M. 05/08/2015, Annex III, Table 1.

The procedure to calculate the components of the staff is as follow:

- a representative number for the number of in-patient people per floor has been considered (> 100 pp for each compartment)
- based on Table 1, it's required the presence of 1 assistant every 20 in-patient persons, so for each floor 6 assistants have been considered;

An extra number of people is required in case of emergency, which has been estimated based on the following assumptions:

- surface of each compartment between 2000 and 4000 m² (Coefficient A =1)
- fire-fighting height > 32 m and protected staircases (Coefficient B = 1)
- Total number of beds for patients up to 1000 (Coefficient C = 6)
- Detection system distributed in the whole structure (Coefficient D = 0.5)
- The formula applied to estimate the number of extra people required is: (A + B + C) * D
- The extra staff for emergency is composed of 4 people for each floor.

The total number of assistants per floor is 6, plus 4 people available in case of emergency.

9.2.1 Evacuation

A *single stage evacuation* is the strategy appropriate when building's residents and visitors fall predominantly into the 'independent' category and it may reasonably be expected when the vast majority of people in the building are able to evacuate immediately from the premises to a place of total safety without assistance, and that the small minority who cannot, can be comfortably accommodated with a Personal Emergency Evacuation Plan.

In healthcare buildings, particularly in-patient access areas, the immediate and total evacuation of the building in the event of fire may not be possible or desirable. Patients with restricted mobility, patients who use wheelchairs, and patients confined to bed cannot negotiate escape routes, particularly stairways, unaided. Patients under medication may require staff assistance, and patients who are dependent on electrical/mechanical equipment for their survival cannot always be disconnected and moved rapidly without serious consequences.

In the healthcare premise, should evacuation become necessary, it will be based on the concept of **Progressive Horizontal Evacuation**, with only those people directly at risk from the effects of fire being moved.
In case of emergency, only the persons present in the incident compartment will evacuate.

In order to apply the Progressive Horizontal Evacuation, an effective response to any fire emergency depends on the preparedness of all the ones involved (staff) and a detailed knowledge and understanding of the fire emergency action plan and the arrangements in place to safeguard building occupants. To achieve such a level of preparation, a considerable effort is made in the form of planning, training, practising and testing the arrangements in place.

The Healthcare premise is divided into compartments, so as to avoid the propagation fire.

There are two main stages of evacuation strategy supposed:

- Stage 1 – horizontal evacuation from the compartment where the fire originates to a Safe Area (Refuge) on the same floor;
- Stage 2 – vertical evacuation to a floor substantially remote from the floor of origin of the fire (at least two floors below), or to the outside through evacuation lift.

Impaired occupants may experience severe difficulties negotiating exit stairways during an evacuation, including not being able to traverse the stairways.
In addition, occupants with disabilities have also been observed to require longer times and frequent rest stops during evacuation; evacuation elevators are one of the most significant means to improve the evacuation capability of mobility impaired occupants.
Lifts are considered a mean of escape and they give the following benefits:

- Effective evacuation of non-ambulant persons
- Reduction in stair congestion and help decreasing the evacuation time

9.2.2 Results

The results of the simulations are summarized below.

<u>Scenario 1 – Basement Fire</u>

The Basement is considered as a unique compartment, so in case of fire the whole floor has to escape. In **Figure 15** the layout of the Basement with the available evacuation means are represented.

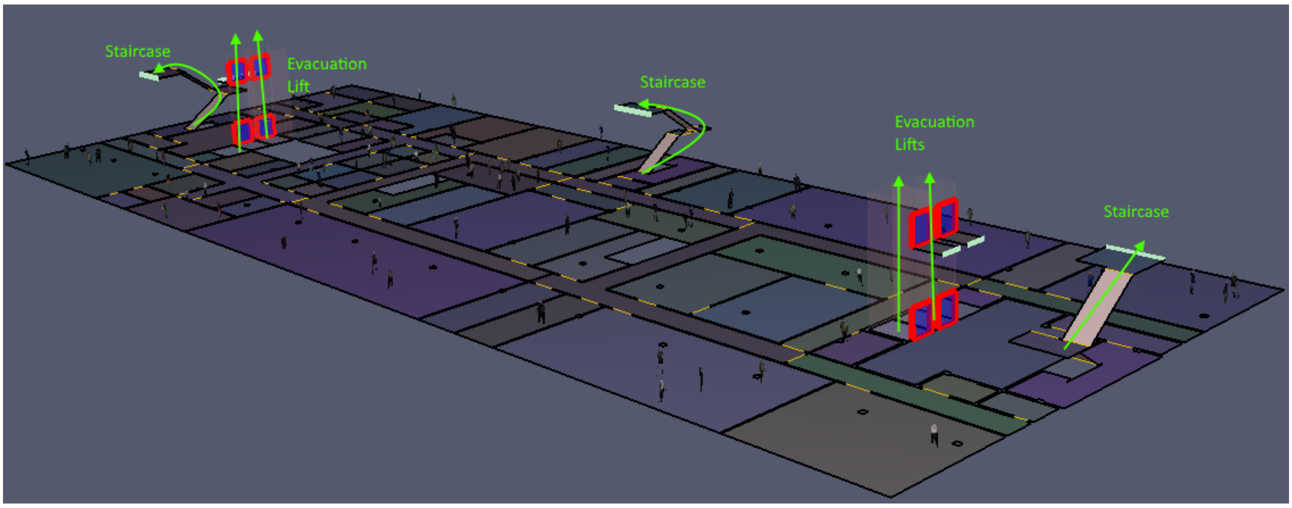


Figure 15 - Layout Basement

As shown in **Figure 15** people can use three staircases and four evacuation lifts located on the two opposite sides of the building. In the Basement two safe areas are present in the zone adjacent to the evacuation lifts, represented in **Figure 16**. The occupants are supposed to be familiar with all the means of escape available.

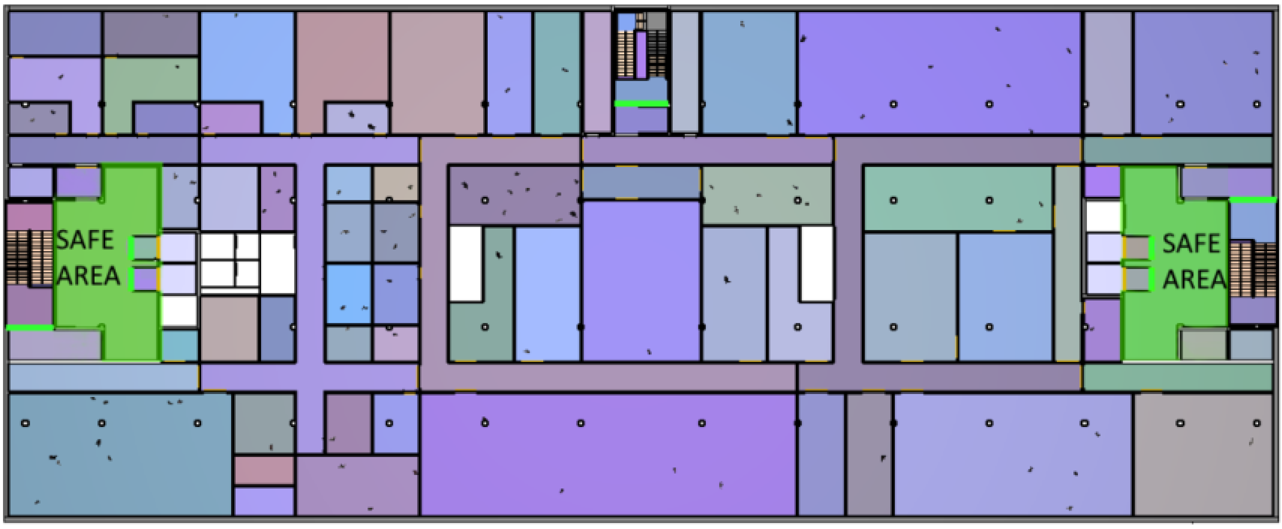


Figure 16 - Location of the safe areas

The total amount of occupants supposed to be present in the Basement is 87 people, divided in people located in the storage rooms (46 people) and the ones located in the offices (41 people).

The detection time estimated with a CFD simulation is around 50 s and the pre-movement time after the alarm starts is considered to be 30 seconds, due to a good training provided to occupants.

The time necessary to reach a place of relative safety is around 140 s and the time to reach the ground floor is around 205 s. Those times take in account both the detection time and the pre-movement time.

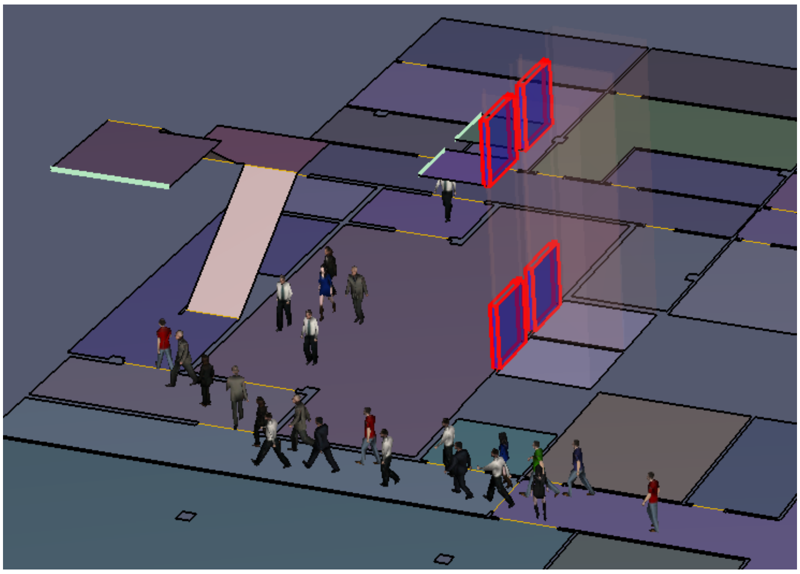


Figure 17 - Basement evacuation

Scenario 2 – Hall Fire

The ground floor is divided in different compartments, each of one can use a different mean of escape (**Figure 18**):

- People in the common areas are supposed to be familiar only with the public entrance of the health-care premise; so, during an emergency they are supposed to use only the front and the back main entrances;
- In-patient people need assistance to escape, so there will be a trained group dedicated to bring those patients to the safe area in case of emergency;
- People in the office will instead use the lateral exits which are the one close to them.

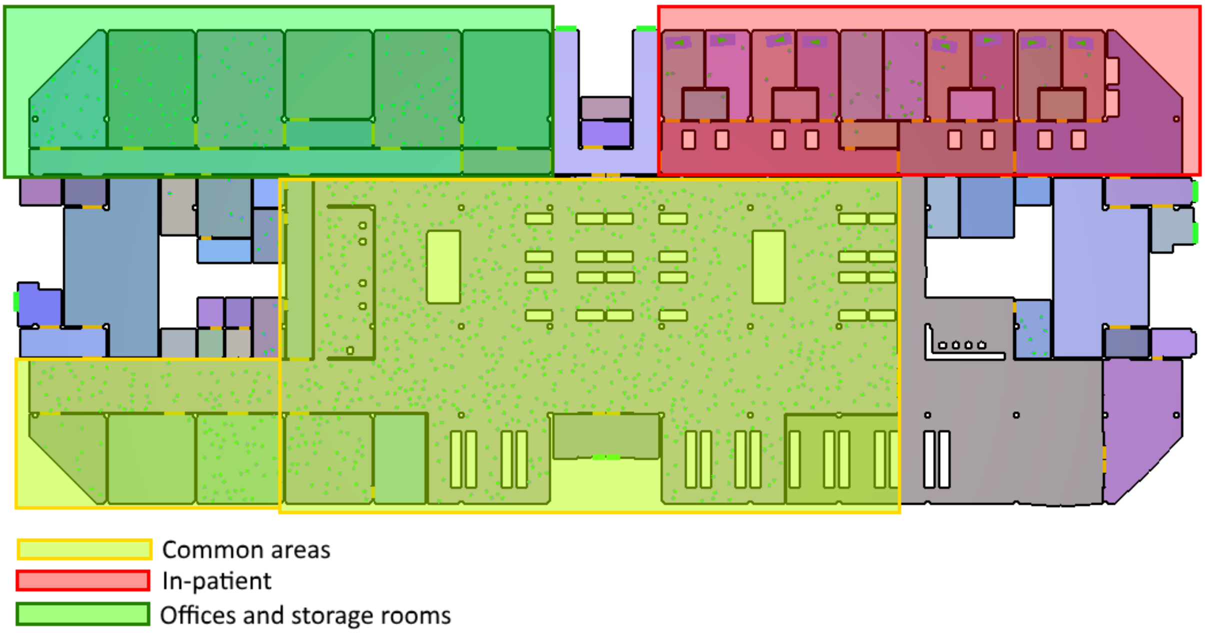


Figure 18 - Layout Basement

As shown in **Figure 19** three main exits are available (2 on the back and 1 on the front of the building), plus three secondary exits. As for all floors, two safe areas are located on the two opposite sides of the building.

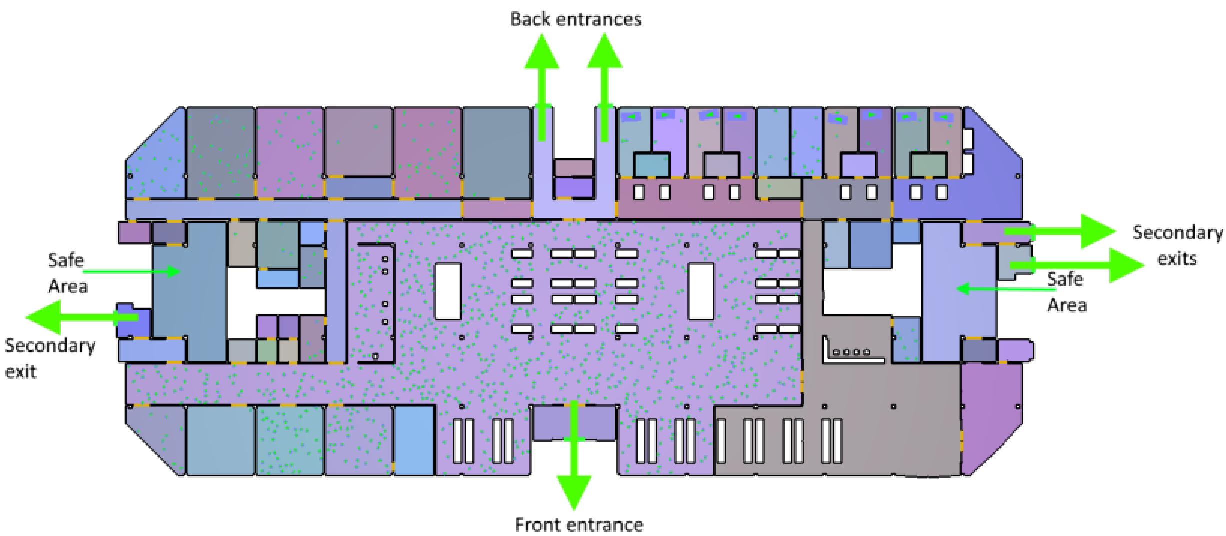


Figure 19 - Exits means available

The total amount of occupants supposed to be present on the Ground Floor is 1079 people.

The detection time estimated with a CFD simulation is around 165 s and the pre-movement time after the alarm starts is considered to be 30 seconds for the staff thanks to a good training, 60 s for the visiting people present in the common areas and 10 seconds for the assistants.

The time necessary to evacuate the full floor meaning either going outside or reaching a place of relative safety is around 400 s; for in-patient people this mean to have reached a safe area (**Figure 20**).

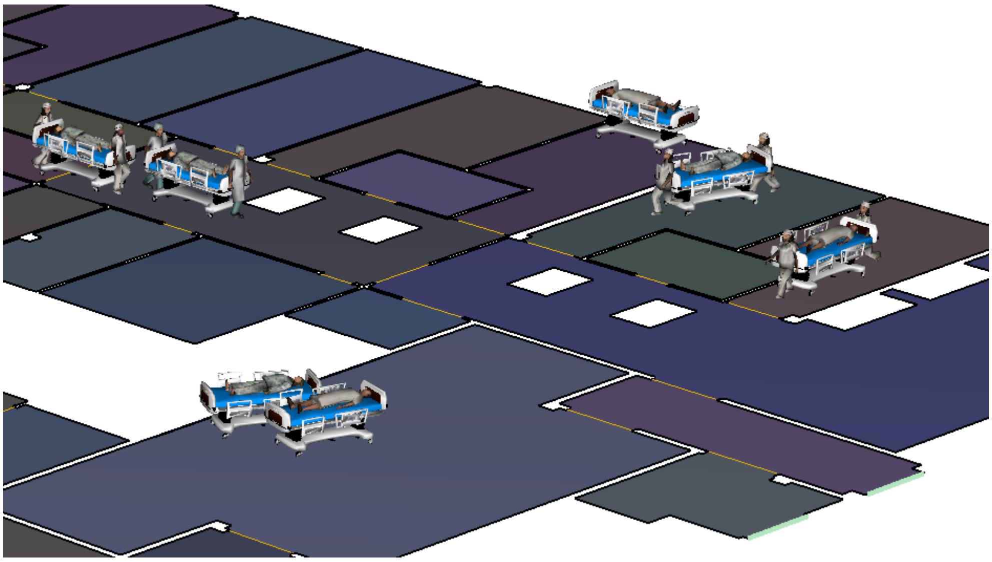


Figure 20 - Assisted in-patient people

The total evacuation time to empty the only compartment affected to fire would be around 400 s as well, this is due to the fact that the used evacuation paths are different for internal people than for visitors.

Scenario 3 – Kitchen fire

The kitchen is located on the first floor; as shown in **Figure 21** there are three staircases available for evacuation and 4 evacuation lifts, two for each side of the building.

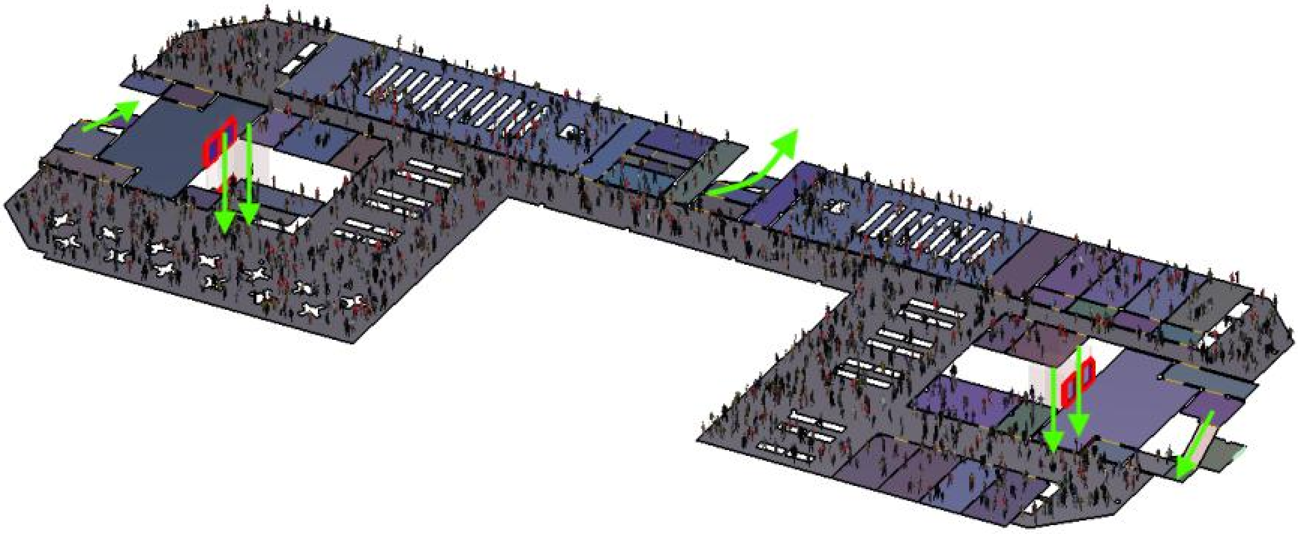


Figure 21 - Layout First floor

Two safe areas are present in the zone adjacent to the evacuation lifts.

The total amount of occupants supposed to be present on the first floor is 1391 people, divided in people located in the auditorium (214 pp), common areas (984 pp) and the ones located in the offices (193 people). A total floor evacuation has been analysed.

The detection time estimated with a CFD simulation is around 80 s and the pre-movement time after the alarm starts is considered to be 60 seconds.

The time necessary to reach the ground floor is around 470 s; this time takes in account both the detection time and the pre-movement time.

Scenario 4 – Patient room

As shown in **Figure 22** there are three staircases available for evacuation and 4 evacuation lifts, two for each side of the building. Two safe areas are located on each side of the building and have a surface sufficient to contain all the in-patients people in a compartment.

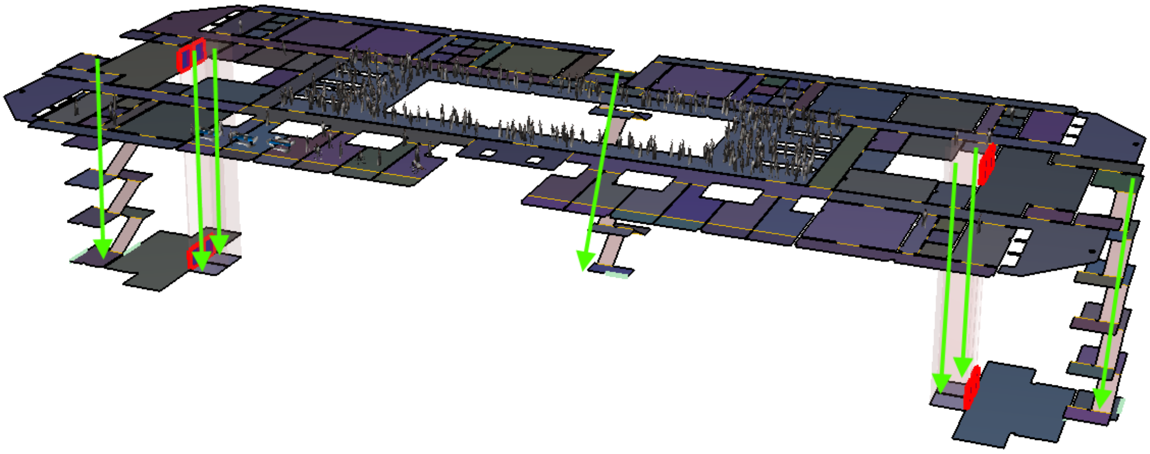


Figure 22 - Fifth floor layout

For a fire in a patient room a phased evacuation strategy is put in place; the evacuation starts from the compartment in which is the fire, afterwards all the others will be evacuated. In **Figure 23**, the location of the fire in the incident compartment is represented with a red triangle; the part of the building which evacuate in case of a fire in that location are the ones highlighted in red.

Figure 23 – Fire location

The staff available in the compartment will activate the evacuation and will assist the in-patients people; in total 10 people are available on each floor, but if necessary assistants from the other floors can help in the evacuation procedure.

In the incident compartment it has been assumed that there are three people which cannot move and require assistance and three other moving with the wheelchair; the in-patients people will be brought to the safe area by the assistants, while people on wheelchairs will reach the safe area independently.

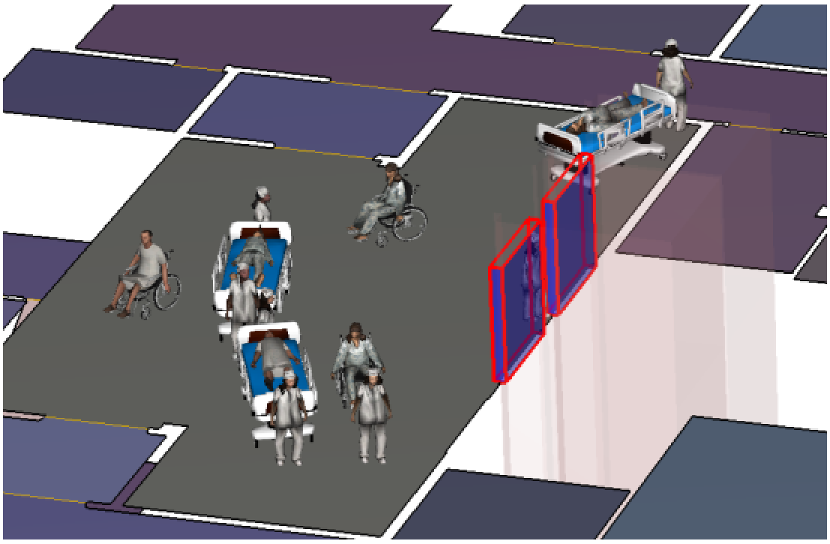


Figure 24 - Safe area

People are considered safe ones they reach either the safe area or any position two floors below the incident one.

For the assistants, the pre-movement time after the alarm it's supposed to be around 10 seconds, those people are distributed uniformly on the floor, so they require a certain time to reach the patient rooms.

In the central hall there are 310 people which have a pre-movement time of 1 minute after the alarm. On the same floor there is a treatment room which will not be evacuated, but there will be a safe in place procedure, so that the treatment room itself is considered a safe place.

The detection time estimated with a CFD simulation is 50 s; the time to evacuate the compartment with the fire and reach either another compartment or a safe area is 195 s.

Scenario 5 – Office

As shown in **Figure 25** there are three staircases available for evacuation and 4 evacuation lifts, two for each side of the building. Two safe areas are located on each side of the building.

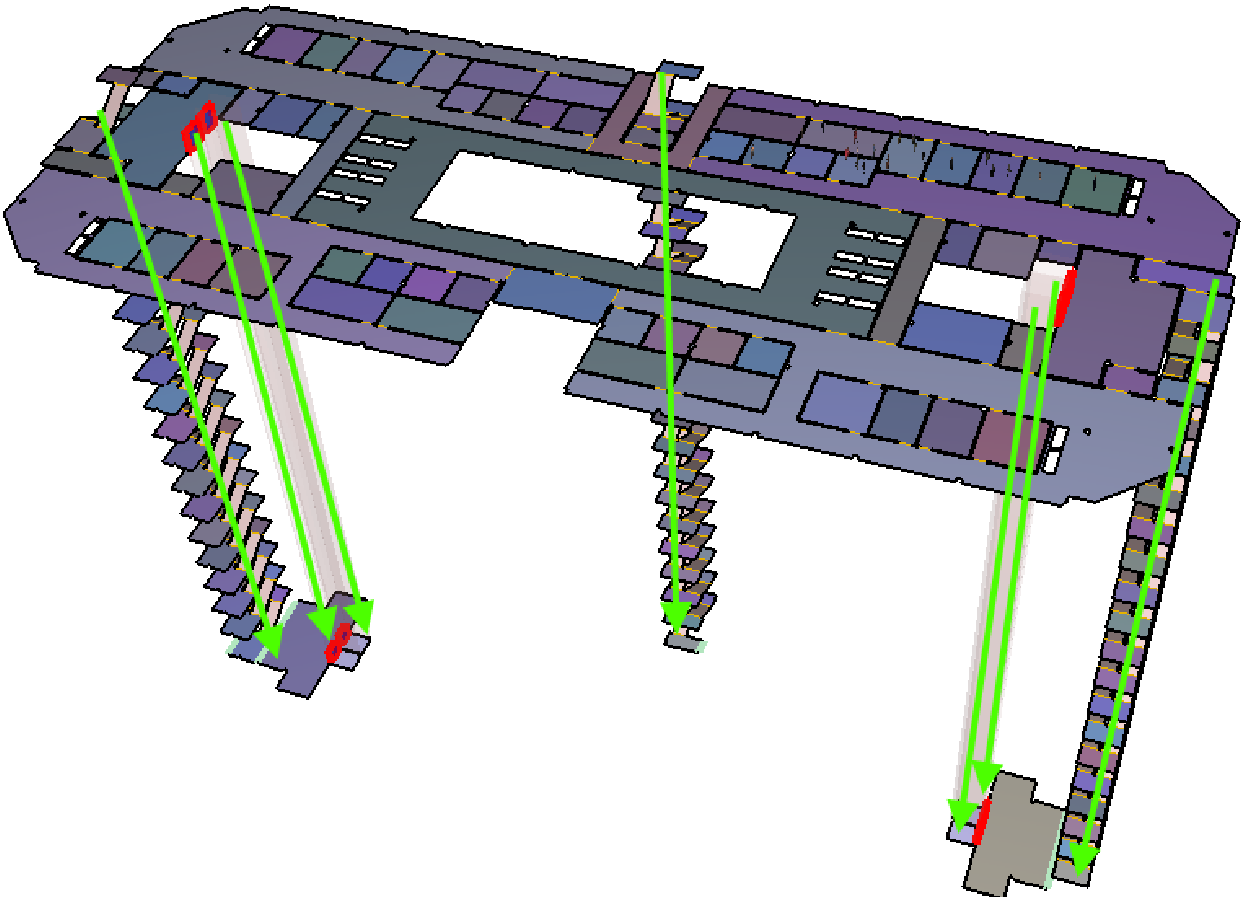


Figure 25 - 13th floor layout

In the office a sprinkler system is installed. A phased evacuation strategy is put in place: the evacuation starts from the compartment in which is the fire, afterwards all the others will be evacuated.

For a fire in an office located on the upper floors (13th to 16th) a phased evacuation strategy is put in place; the evacuation starts from the compartment in which is the fire, afterwards all the others will be evacuated. In **Figure 26**, the location of the fire in the incident compartment is represented with a red triangle; the part of the building which evacuate in case of a fire in that location are the ones highlighted in red.

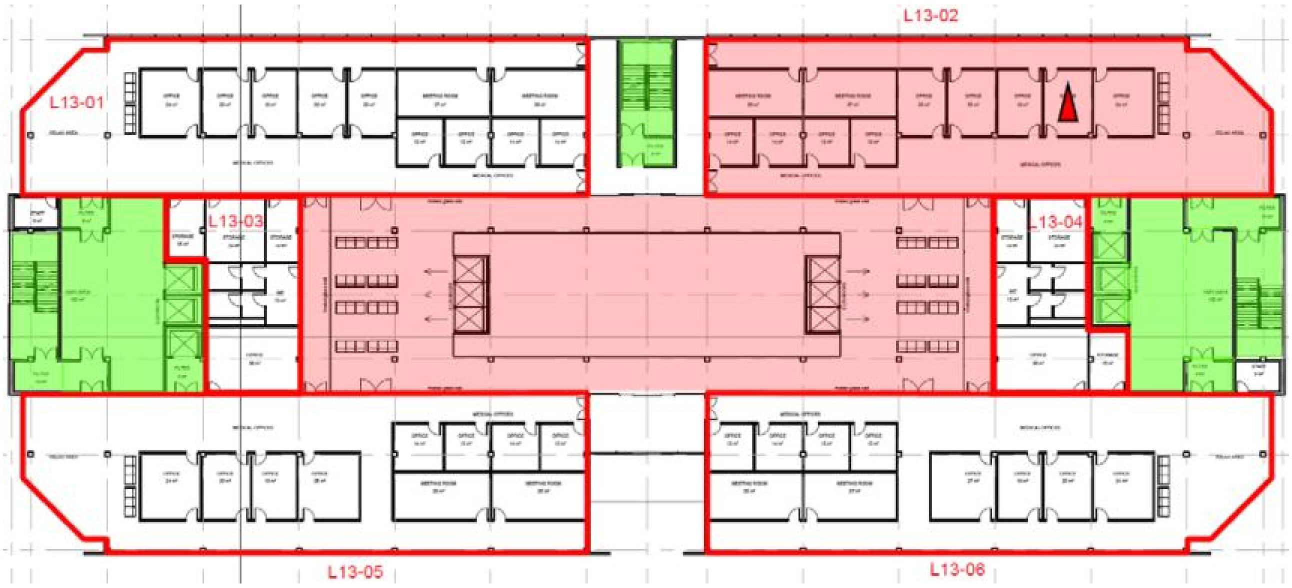


Figure 26 – Fire location

In **Figure 27**, the usage of the evacuation lifts is shown.

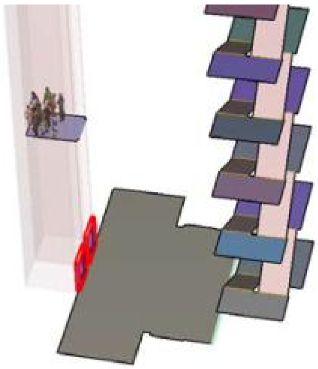


Figure 27 - Evacuation lift in use

People are considered to be safe ones they reach either the safe area or any position two floors below the incident one.

In total 335 people are present in the incident compartment, divided in 29 people in the medical offices and 306 people in the central common area.

The pre-movement time after the alarm it's supposed to be around 30 seconds, due a good training put in place, for people in the medical offices and 60 seconds for people located in the common area.

The detection time estimated with a CFD simulation is 50 s and the time to evacuate the incident compartment is 120 s e the time to empty the common area would be 265 seconds; since the atrium is always free of smoke people in this area are not considered in danger.

The total evacuation time to empty the incident compartment is 170 s.

9.3 ASET vs. RSET

Achievement of criteria for people safety:

Table 40 - Achievement of criteria for people safety

Scenario	RSET	ASET	RSET<ASET
Basement fire	140 s	300 s[2]	√
Hall fire	400 s	900 s	√
Kitchen fire	470 s	900 s	√
Patient room's fire	250 s	900 s	√
Office fire	170 s	300 s	√

The fire brigade can perform a safe intervention if there is an access free of smoke that let to reach the fire location and start the extinguishment. The fire brigade is supposed to intervene after 15 minutes from the start of the fire.

In the following table the achievement of performance criteria for fire-brigade safety is shown:

Table 41 - Achievement of criteria for fire brigade safety

Scenario	Time for untenable condition to take place	Safe condition for intervention
Basement fire	900 s[3]	√
Hall fire	900 s	√
Kitchen fire	900 s	√
Patient room's fire	900 s	√
Office fire	900 s	√

Given the results the building is safe in all the case scenarios.

[2] At 300 s one of the two safe areas in blocked due to a low visibility (<10 m)
[3] Even though the visibility decreases with the fire development there is always one rescue lift which is completely free of smoke and let a safe intervention to take place

10. Fire Safety Management

An effective fire safety is composed both of technical fire precautions and a strong management system. The main challenge in a healthcare environment consists on the fact that many occupants require some degree of assistance to ensure their safety in the event of a fire.

A good safety management ensures that:

- The impact of a potential fire is minimised;
- The technical fire protections are maintained in operation;
- The staff can respond effectively to the fire.

In an environment with dependency patients is fundamental to have a trained staff which can apply the emergency action plan.

The emergency evacuation plan will be maintained and tested regularly so that emergency responders know what to do and what to expect if an emergency arises; the evacuation plan is fundamental when using a phased evacuation strategy or a defend-in-place one.
Having an effective plan directly impact the outcome of an emergency.

Practice drills should be held regularly to keep employees prepared and increase their familiarity with evacuation procedures and the building maximizes the potential for a successful evacuation.

11. Active fire protection

The design and construction of the healthcare building should:

- provide sufficient resistance to the effects of fire and maintain its structural stability to provide adequate time for escape and extinguishment;
- inhibit the spread of fire and smoke within the building;
- inhibit the spread of fire to adjacent buildings.

Active fire protection systems such as detection systems, warning systems and fire suppression systems are incorporated into the building so that the time available for escape is maximised.

The provision of adequate means for detecting a fire and raising the alarm is of vital importance.
In fact, early detection permits time for orderly evacuation and allows the fire to be tackled at an earlier stage, thus minimising the damage caused. Detection is dependent on staff observation, automatic alarm and detection systems.

In the building there is suitably staged fire warning system. A staged fire alarm alerts the staff and occupants of a building to an alarm of fire in stages - the fire alarm may sound an evacuation signal in one part of a building but only an alert signal to the other parts.
After a pre-determined time, the evacuation signal may sound throughout the premises or in progressive stages throughout the building. Such systems require a greater degree of management input to ensure that staff and others are familiar with the system and action necessary.
The alarm will be a voice alarm which gives information on the location of the fire for the staff to start the procedure of evacuation.

A detection system is distributed in the building; in particular, smoke detectors are located in every compartment, in the kitchen located on the first floor a temperature detector system is installed.
The detection system will automatically activate the smoke and heat control system and will let the voice alarm start.

A sprinkler system is installed in the basement, where offices and storage rooms are located, and on the upper floors (13^{th}-16^{th}) where other offices are present. The sprinkler system is fundamental to control the size of the fire and to permit a safe intervention of fire brigade.

Based on the risk analysis a sprinkler system is recommended also for the other floors, this will facilitate the implementation of the phased evacuation strategy.

12. Natural smoke venting of the Atrium

A natural smoke and heat control system has been selected for the atrium, while a mechanical one has been selected for the rooms in which patients cannot be easily moved in case of incident and for the car parking.

The natural smoke and heat control system has been dimensioned based on UNI 9494-1; in case of fire, the smoke and heat control system is used to maintain a smoke free layer by removing smoke from the top of the structure.

Thanks to the installation of a smoke control system:

- The evacuation routes are maintained free of smoke;
- facilitate fire-fighting operations by creating a smoke-free layer;
- delay and/or prevent the "flashover" and therefore the general development of the fire;
- limit damage to facilities and goods;
- reduce the thermal effects on the structures;
- reduce damage caused by combustion gases and toxic and/or corrosive substances originating from combustion.

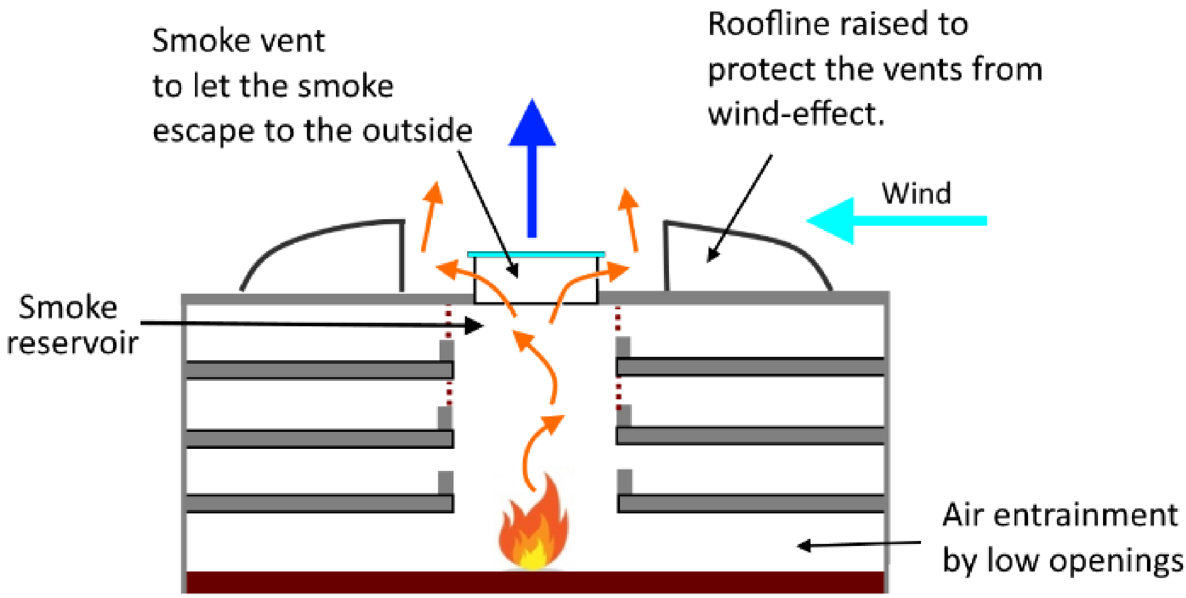


Figure 28 - Natural smoke extraction system

For a fire in the upper floors two extraction shaft are available for each compartment, while the inlet of fresh air will be provided from the atrium by the opening on the roof.

13. Car parking Fire Protection

The car parking is composed of 8 stories, each of whom is considered a separate compartment. The Fire Safety of the adjacent car parking has been done following the Italian Fire Code, which gives the requirements for "garages" in a dedicated chapter.

- The classification of car parking is based on typology, size and height, and for the case study under analysis the classification is as follow:
- Public access (Code SB)
- Surface of each compartment between 1000 and 5000 m^2 (Code AB)
- Height of the car parking between -6 and 24 m (Code HA)

The $Risk_{life}$ for each compartment is B2, where B indicates occupants awake and not familiar with the environment and 2 indicate a moderate growth rate of the fire. Based on the specific risk the class of fire resistance has to be REI60 and the communication with the adjacent health care premise must be through filters which guarantee the isolation of the two building to smoke.

Prohibition and restriction signage has to be distributed in the whole car parking; In the car park it is forbidden:

a) smoking or using open flames;
b) deposit or dispose of flammable fluids, including carrying out operations of filling and emptying of fuel tanks;
c) carry out maintenance, repairs of motor vehicles or engine tests, outside the specially prepared areas;
d) the access of vehicles with obvious fuel losses (specifying, where appropriate, the motivation in the signs);
e) access for vehicles not complying with the maintenance obligations on the circuit fuels.

It is mandatory to intervene quickly on leaks of liquid fuel pouring with the usage of absorbent material (eg: sand);

LPG powered vehicles are allowed if equipped with a safety system compliant with ECE/ONU67-01 regulation.

A basic/manual protection is required, which suppose the installation of a hydrants to protect individual compartments. A smoke and heat control system is provided to guarantee a safe entrance for fire-brigade's intervention, a critical requirement is that the fire brigade must be capable to activate or deactivate the SHC-System based on necessity.

The smoke control system is designed based on the requirements of prCEN/TR 12101-11 "Smoke and heat control systems. Part 11: Indoor vehicle parks".

The smoke and heat control system is necessary also to avoid the impact of a fire in the parking on the health care premise.

14. Conclusion

A performance-based design has been presented for the fire safety design of a new health-care premise of 16 floors connected through a central atrium.

The key design features of the Proposed Design include the use of:

- Strict requirements on fire reaction characteristics of allowed materials in the building to reduce fire load and fire size;
- A voice alarm management system to control and guide occupant evacuation;
- Smoke detectors in the whole building;
- Heat detectors in the kitchen;
- An effective sprinkler system to control the fire growth in the Basement, in the kitchen and in the offices;
- A reliable natural smoke venting system at the roof to allow smoke to vent from the atrium in case of fire on the lower floors (Ground floor and first floor) and fresh air in case of fire on the upper floors. Extraction shafts to evacuate smoke on the upper floors;
- Evacuation lifts for egress purposes on the two opposite sides of the building protected by smoke filters;
- Rescue lifts for fire-brigade intervention protected by smoke filter;
- Phased evacuation strategy supported by a solid management system;
- Defence-in-place strategy for treatment rooms.
- Smoke compartmentation (REI60) to:
  - limit spread of fire and smoke
  - limit the number of occupants exposed to a fire
  - facilitate the horizontal relocation of patients
- Floor-to-floor openings are restricted to limit smoke spread between floors;
- Mechanical smoke and heat control system on the car parking to prevent smoke spread from the parking to the health-care premise;
- Implementation of a Emergency Management system.

The evaluation shows that the Design achieves the fire safety performance criteria set out for the case study.

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Annex

Index

ANNEX A

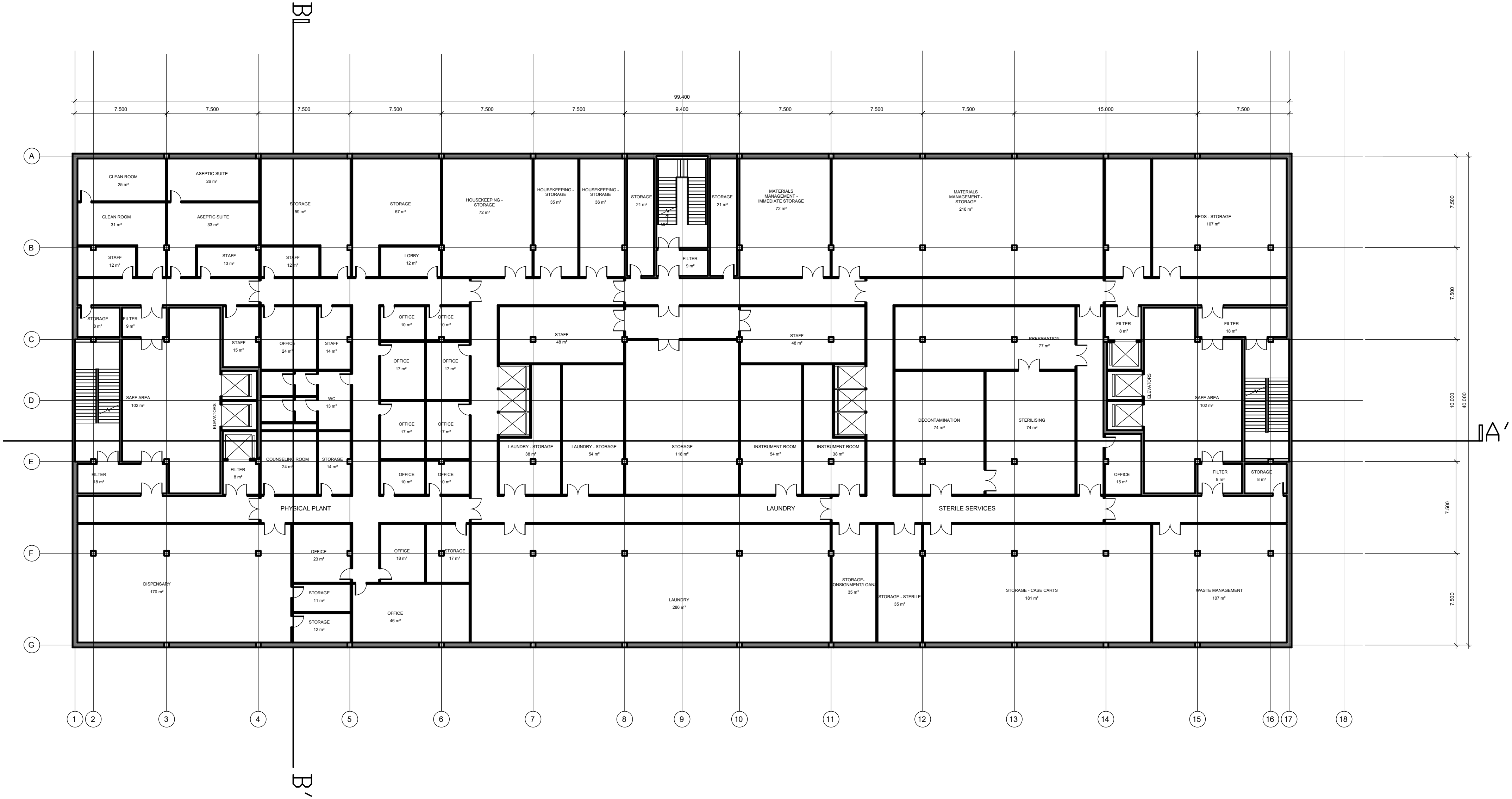
Building plans


EMERGENCY

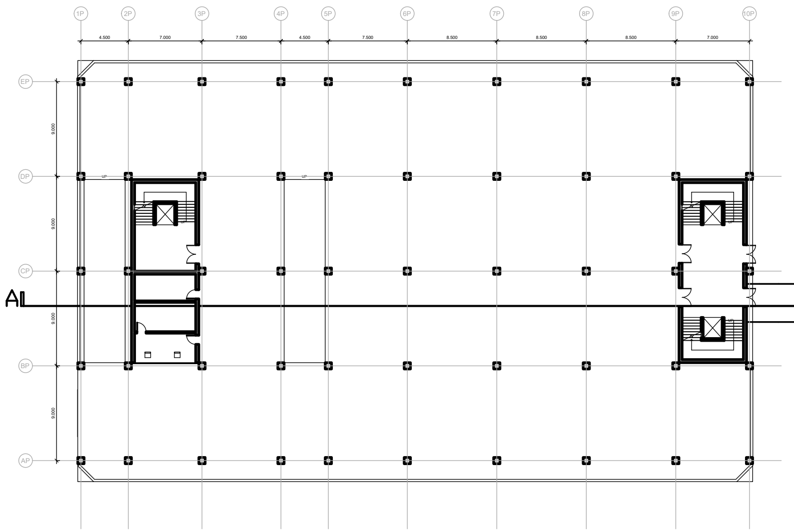

A08
A09
A10
A11

HONOLULU HOSPITAL
PITAL

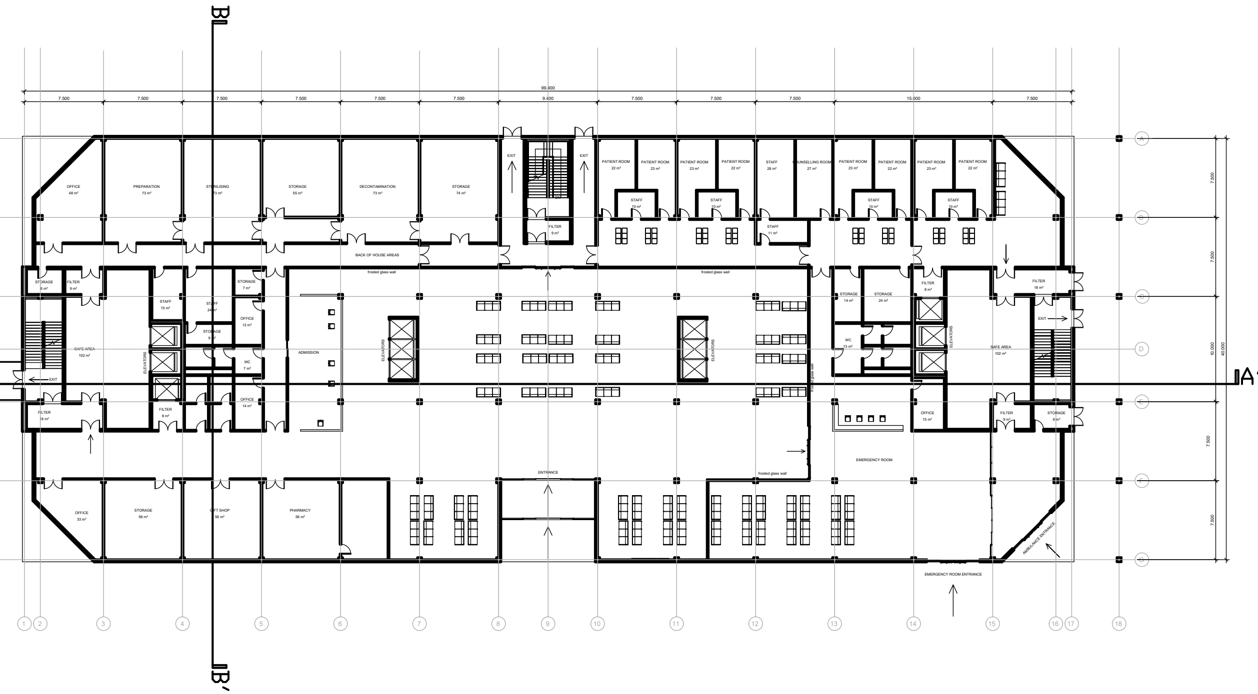
BASEMENT LEVEL_Physical Plant, Laundry, Facilities Department



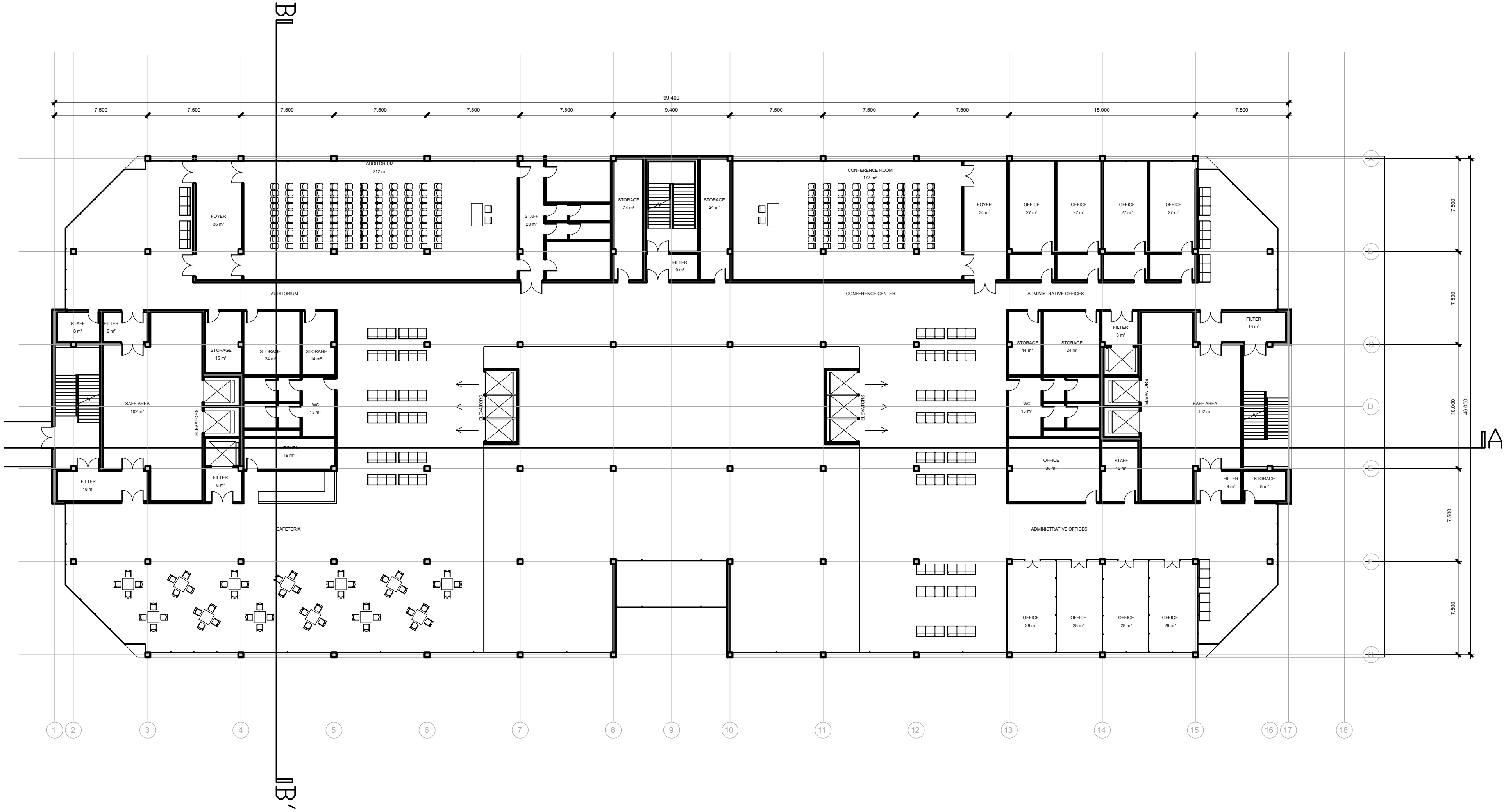
LEVEL 01Park



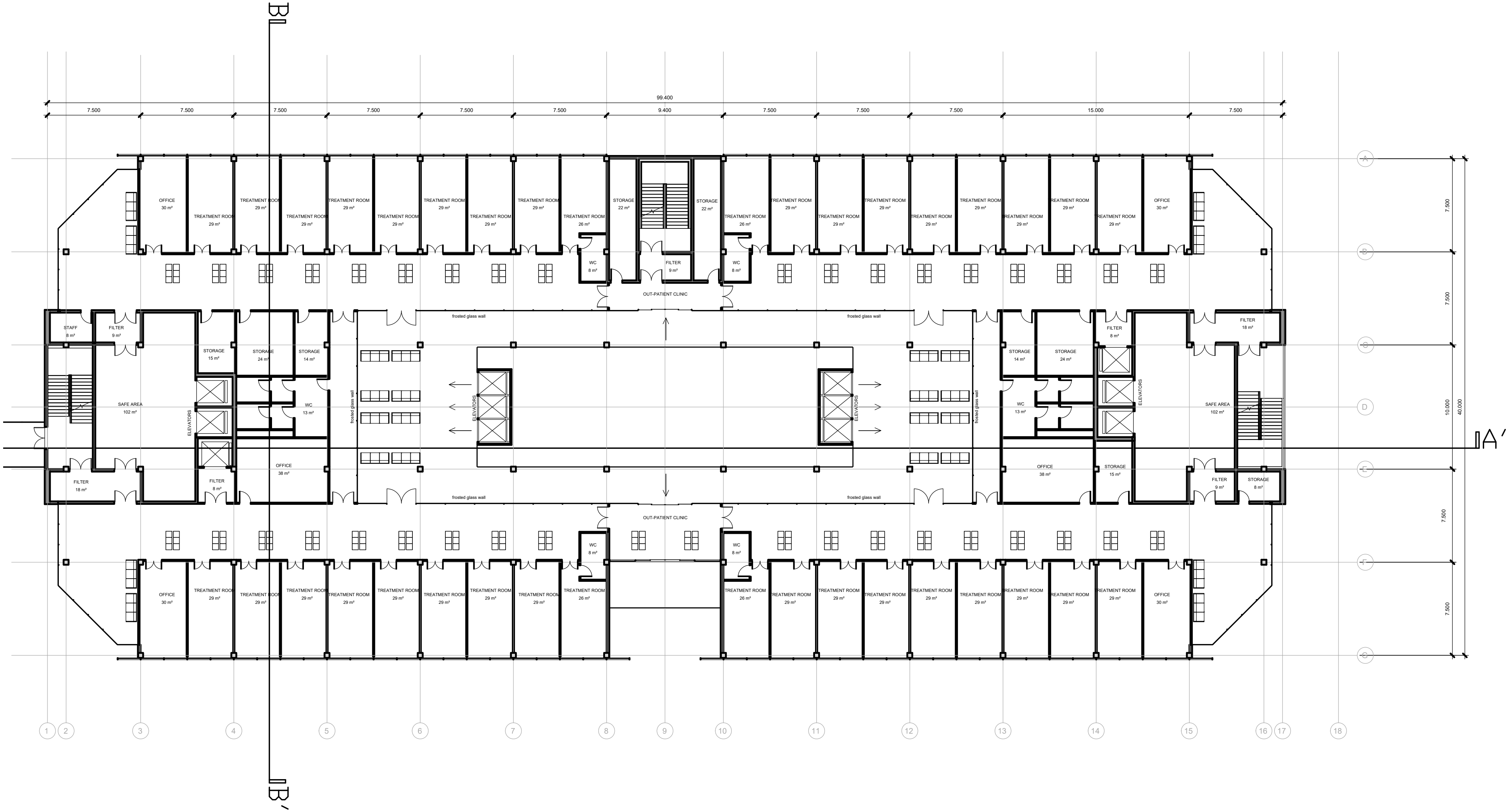
LEVEL 01_Admission, Emergency Room, Pharmacy, Gift shop, Storage



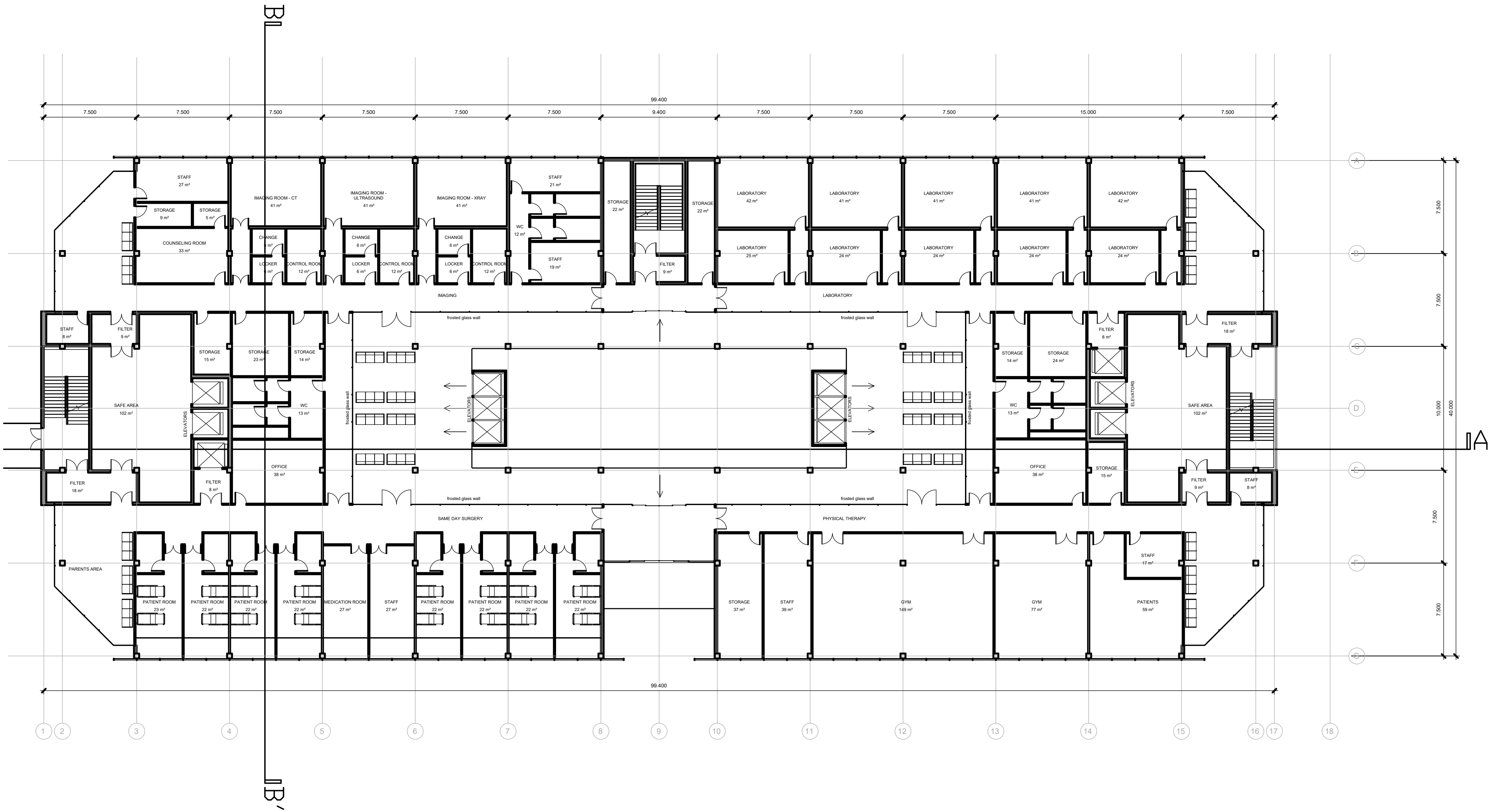
LEVEL 02_Cafeteria, Admistrative Offices, Conference Center, Auditorium



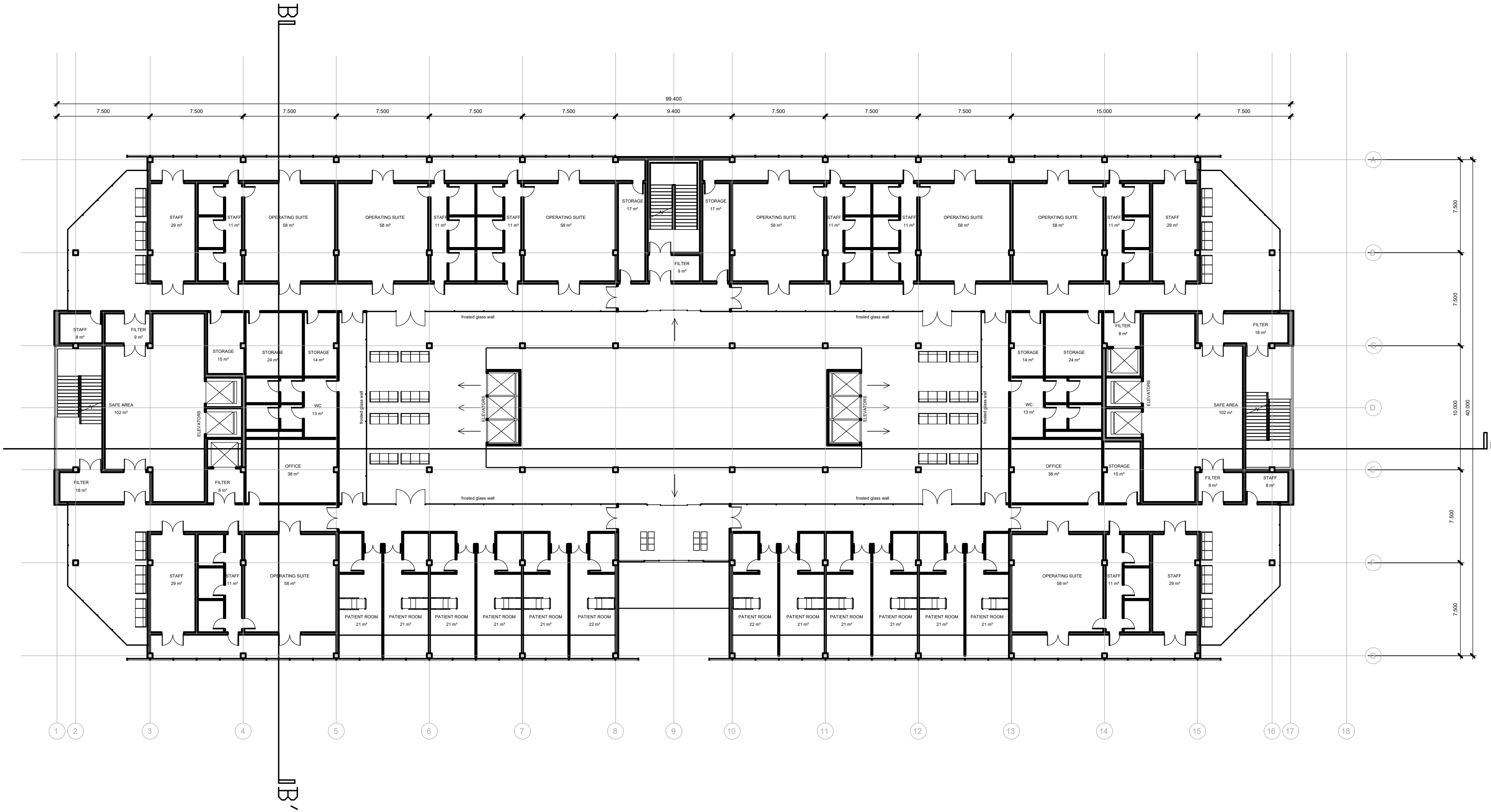
LEVEL 03_Out-Patient Clinic



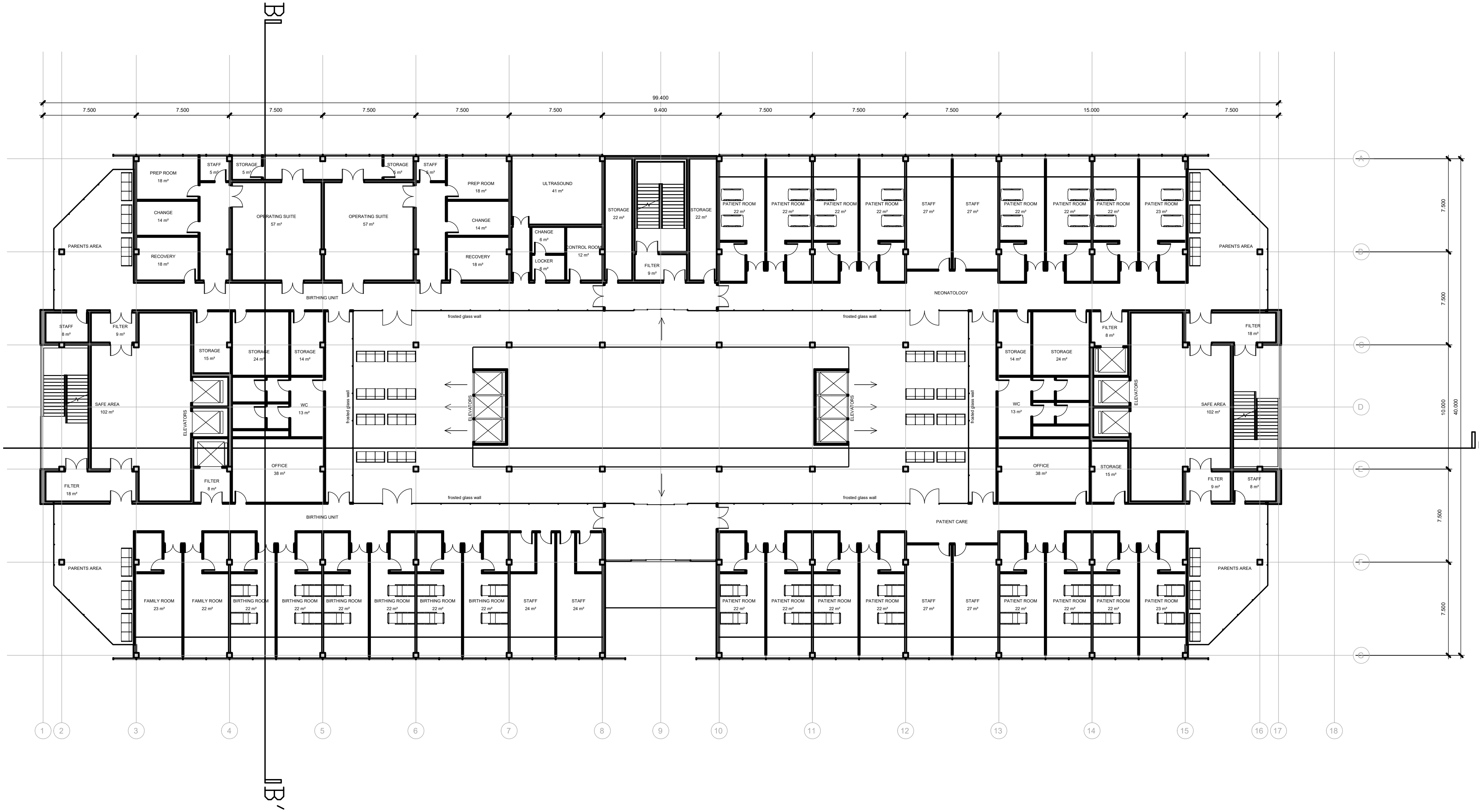
LEVEL 04_Imaging, Laboratory, Physical Therapy, Same Day Surgery



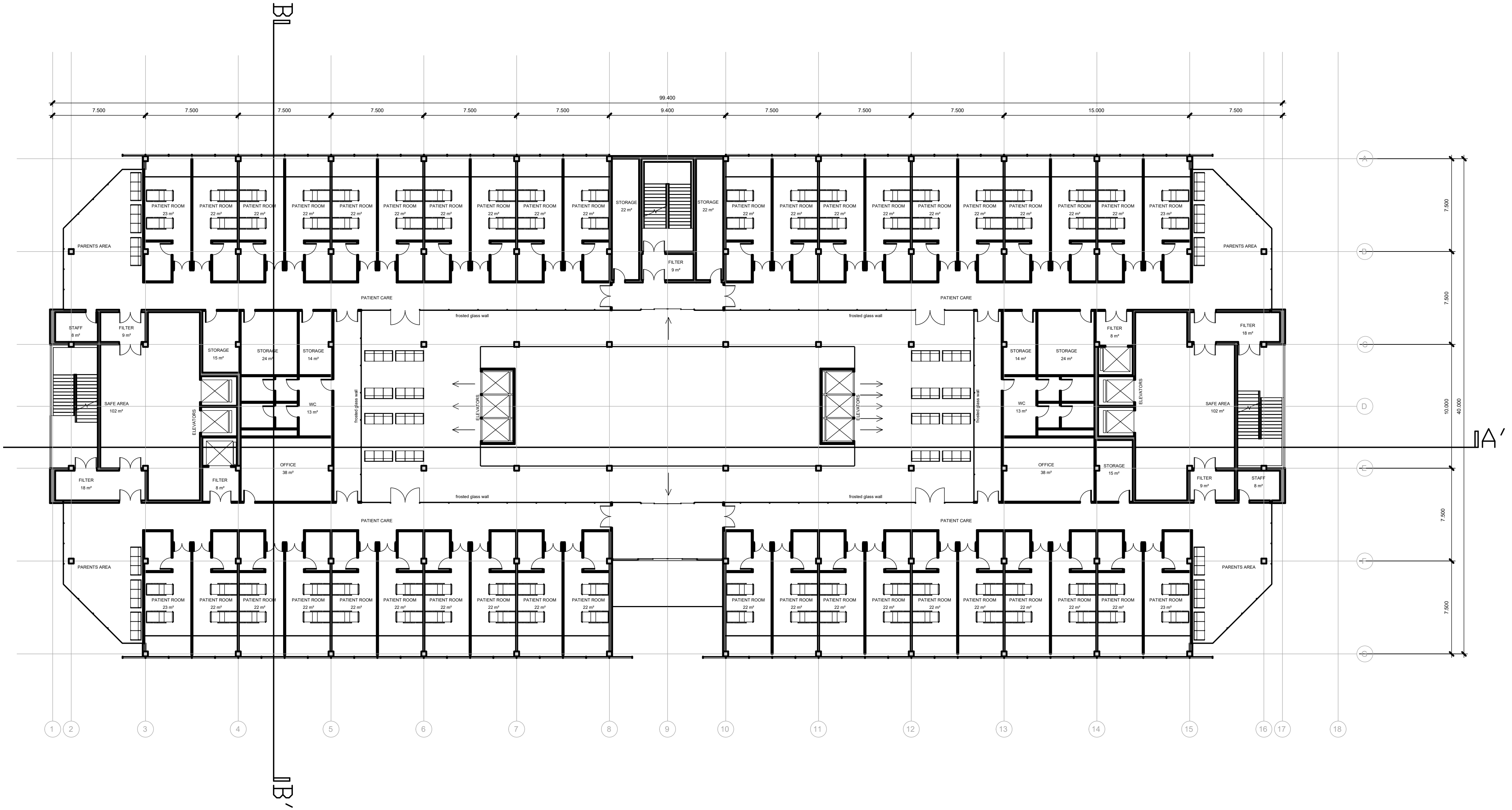
LEVEL 05_Operating Suites, Recovery, Cardio Unit



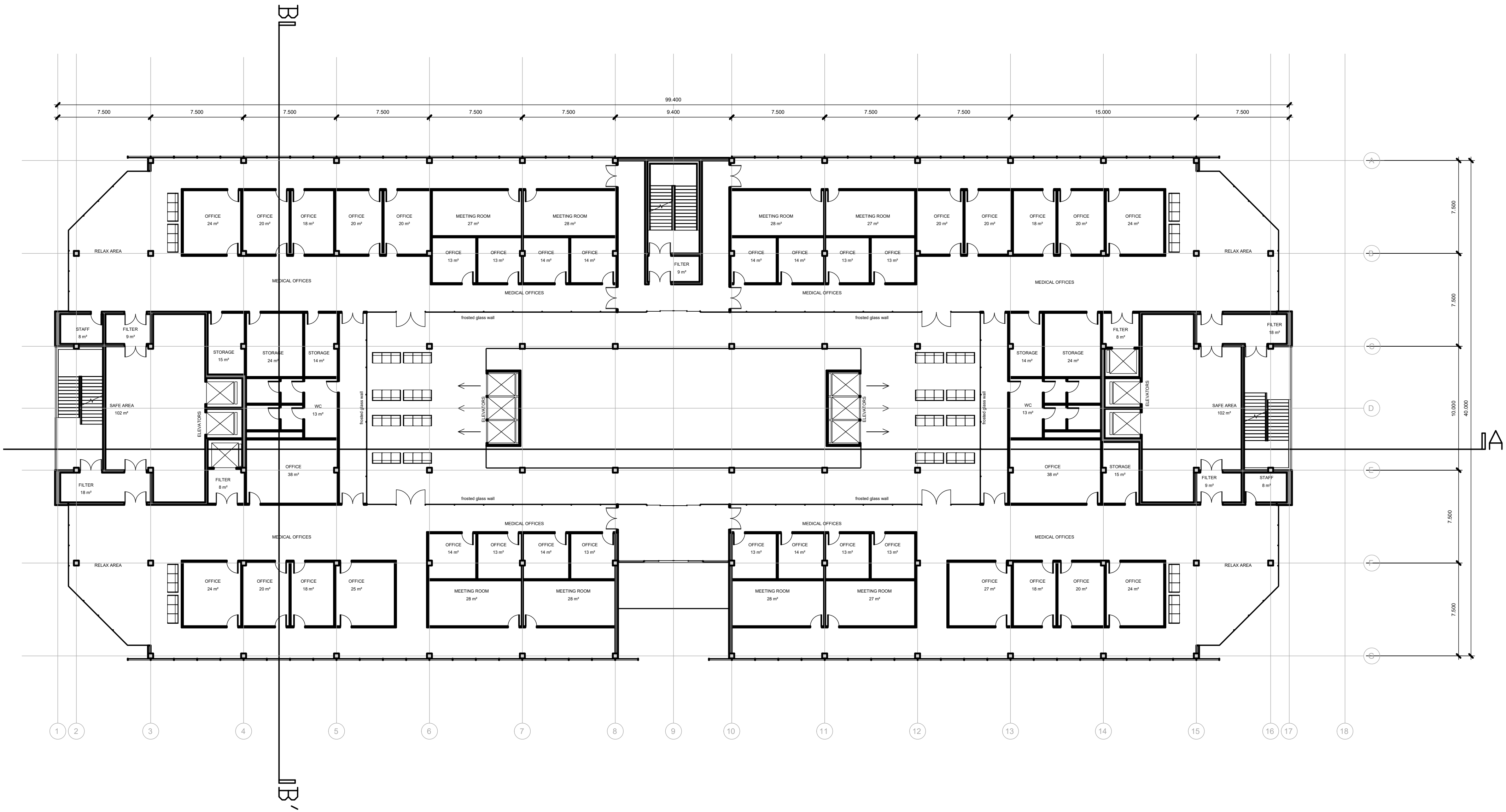
LEVEL 06_Patient Care, Maternity



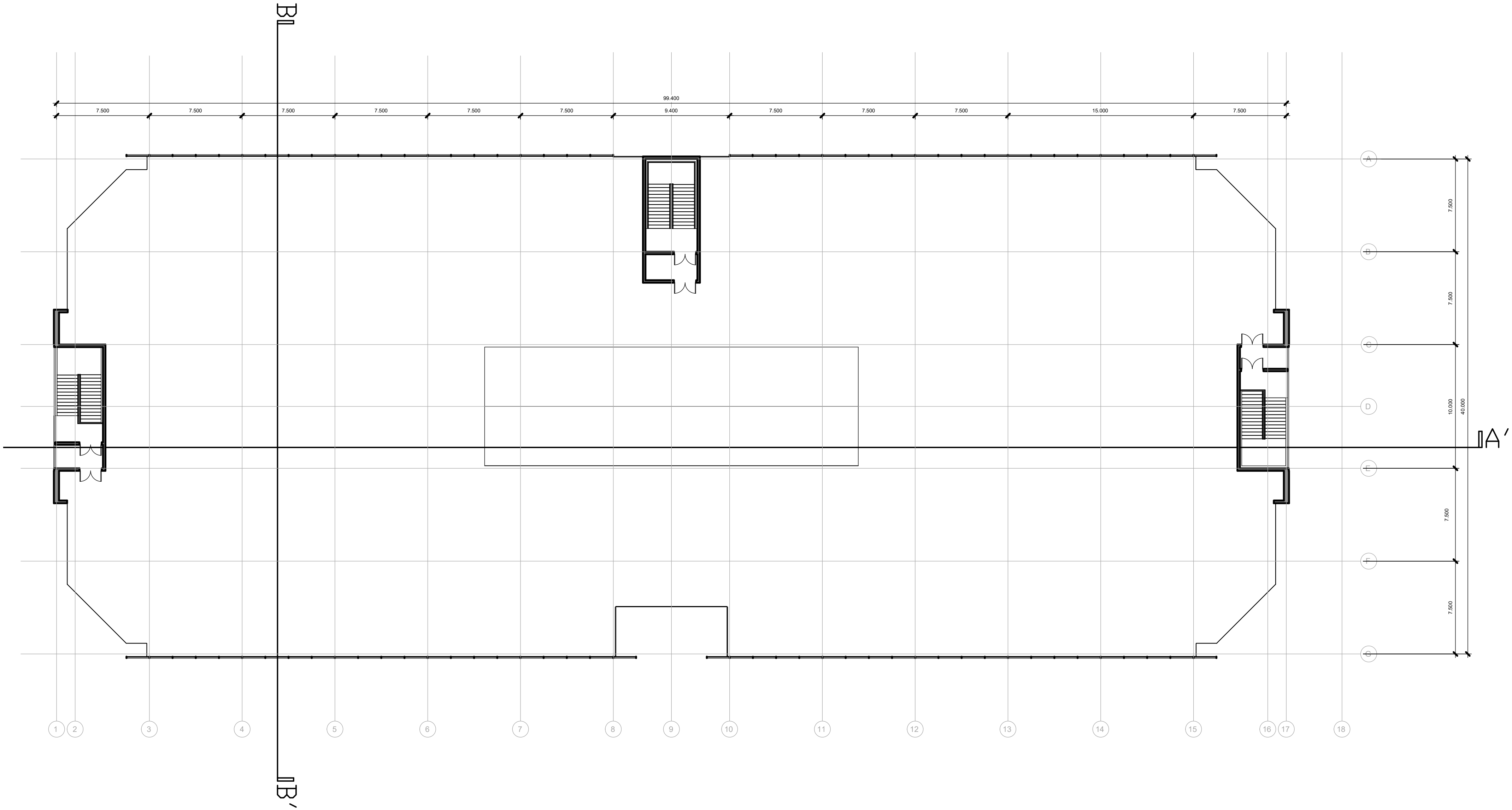
LEVEL 07-12_Patient Care (80 Beds per Floor)



LEVEL 13-16_Medical Offices



ROOF LEVEL



B
B'
A'
99.400
7.500
7.500
7.500
7.500
7.500
7.500
9.400
7.500
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7.500
15.000
7.500
7.500
7.500
10.000
40.000
7.500
7.500
A
B
C
D
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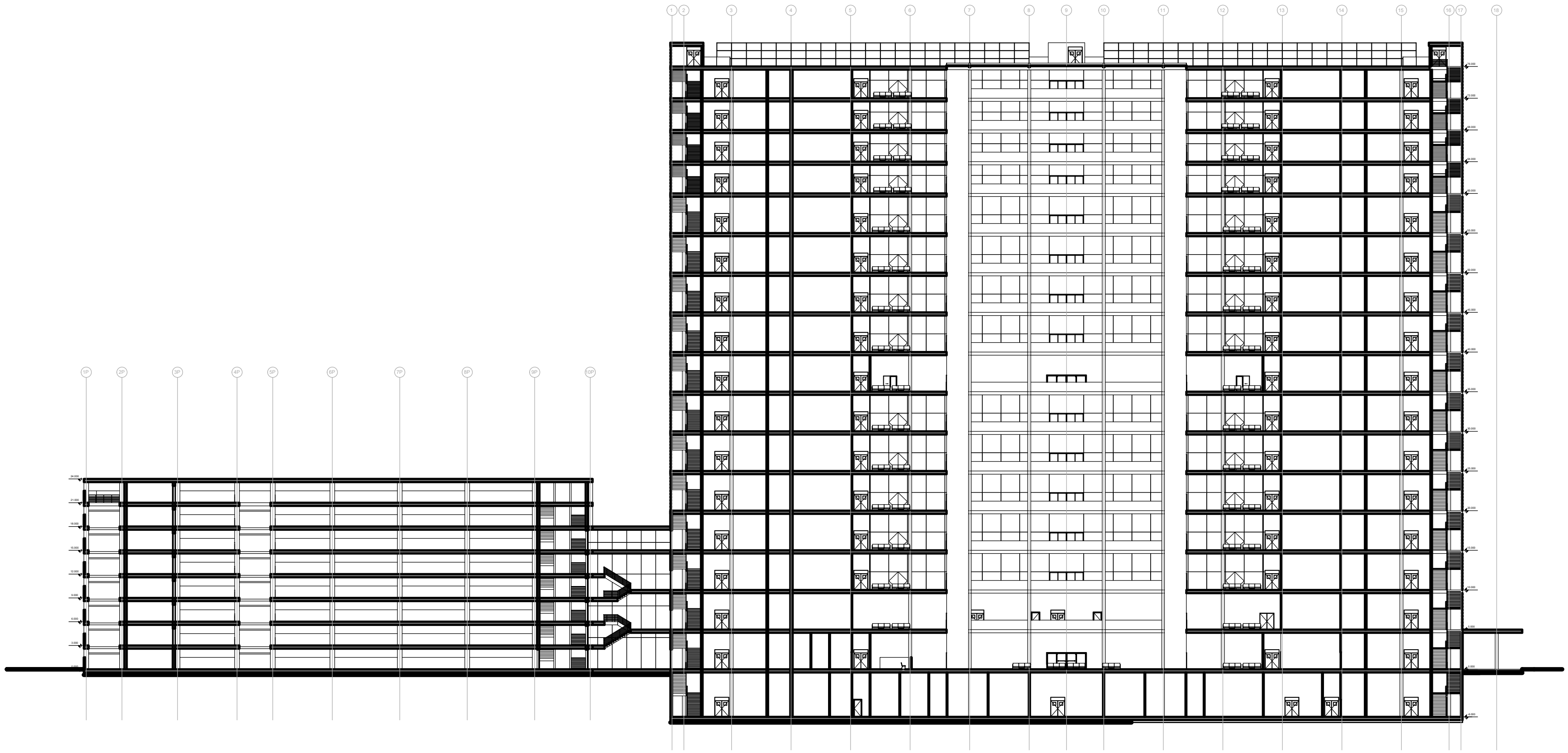
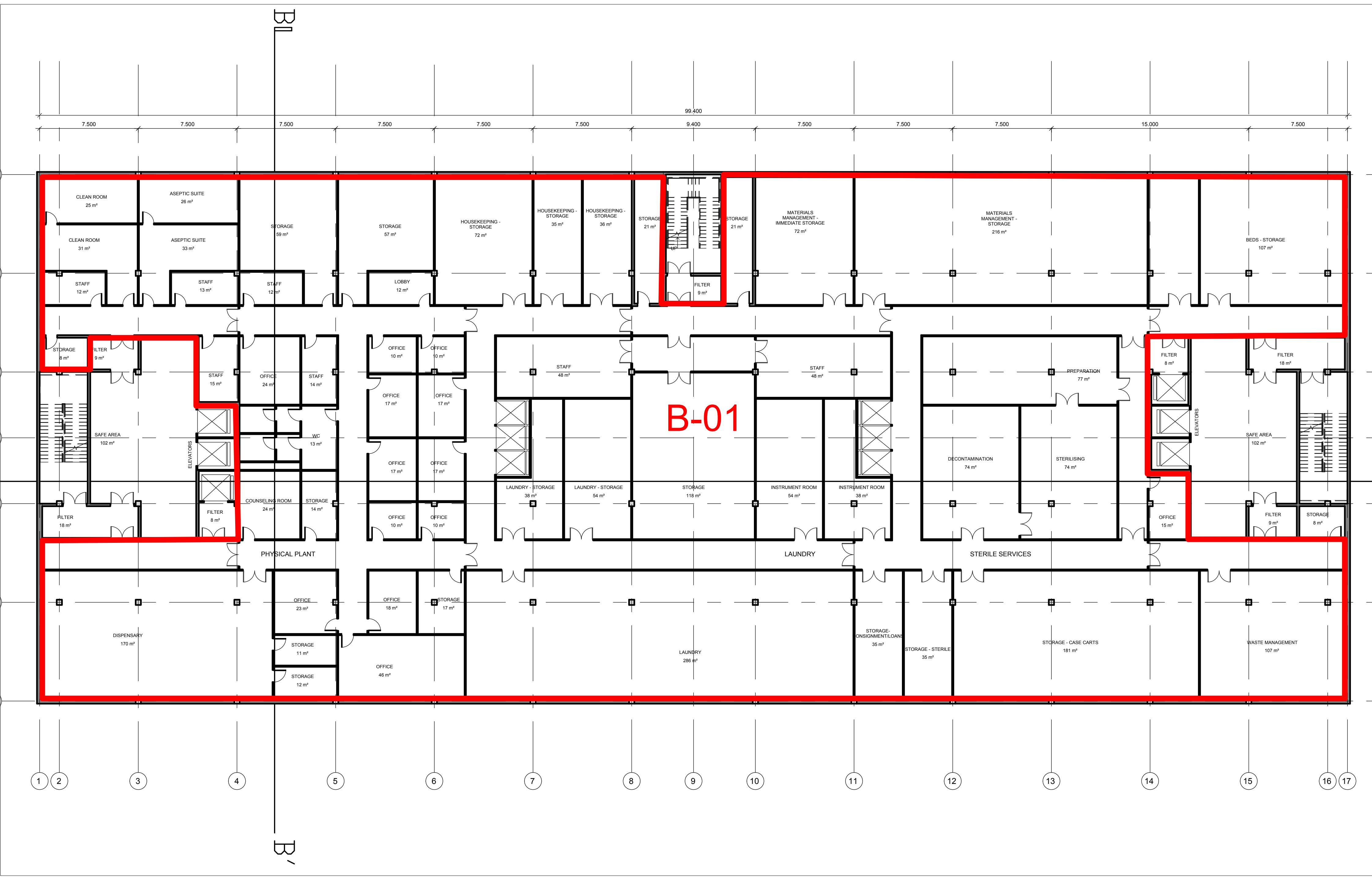


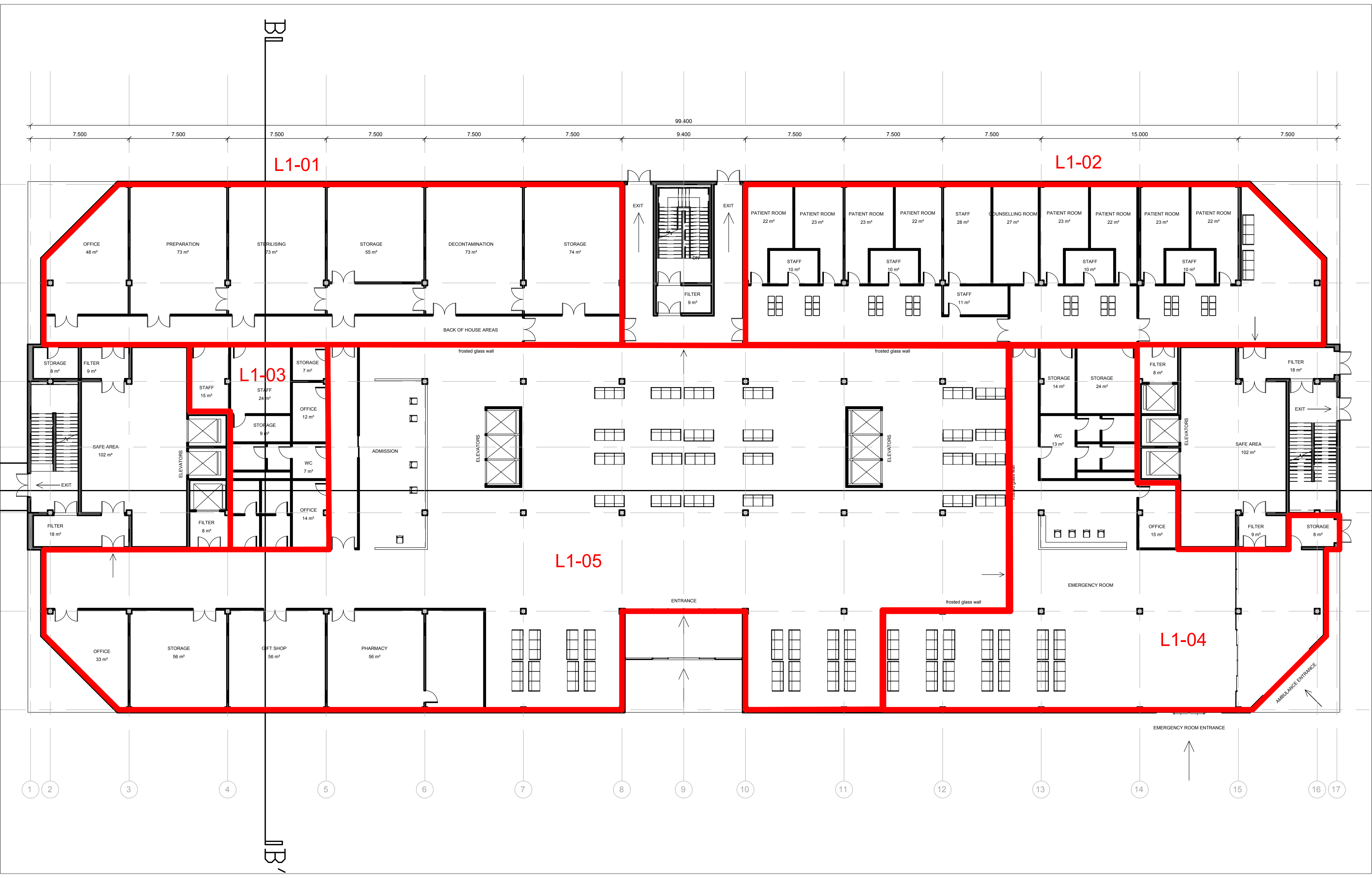
Section A-A'

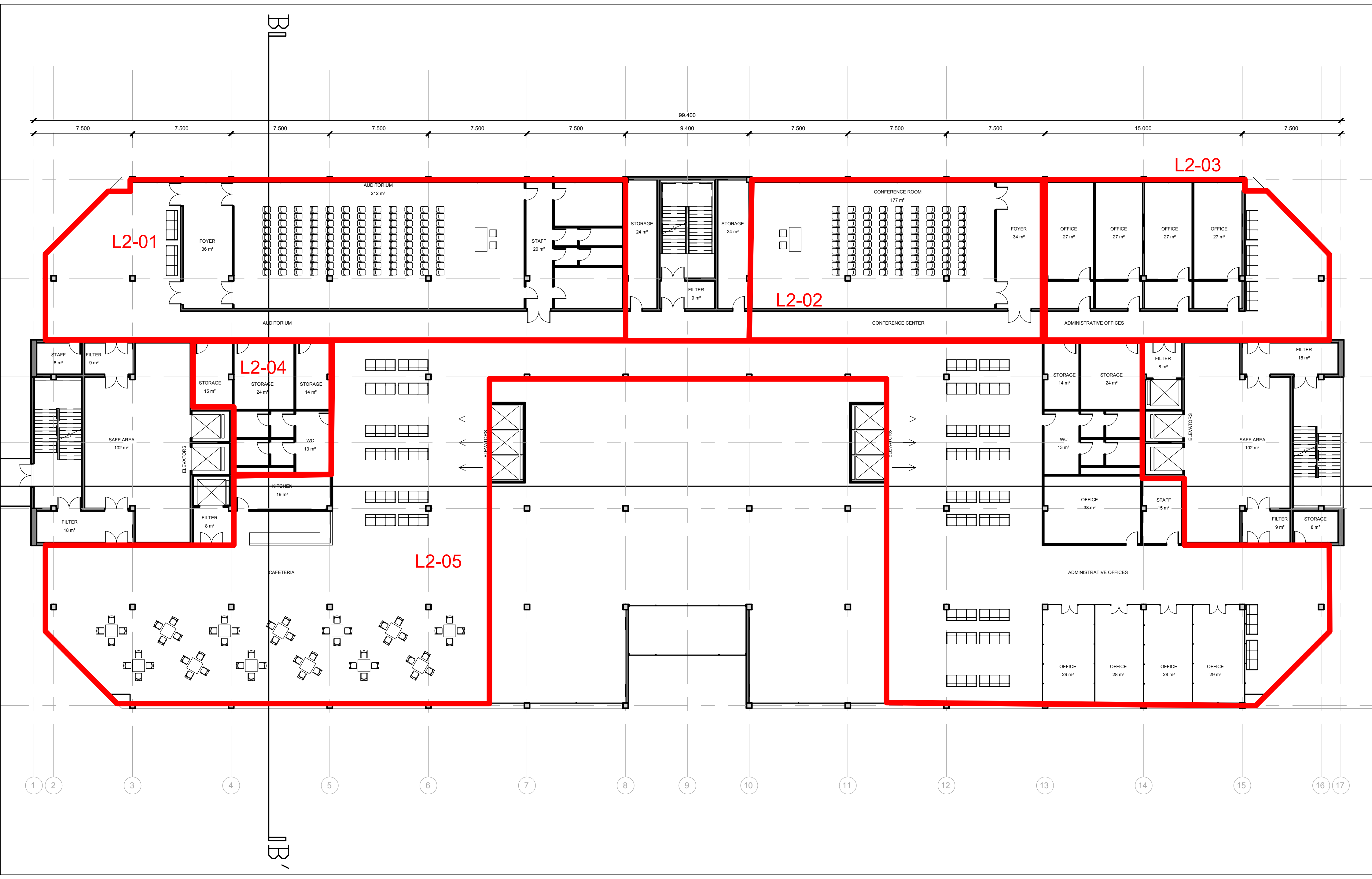
ANNEX B

Compartmentation of building floors



B-01
PHYSICAL PLANT
LAUNDRY
STERILE SERVICES
CLEAN ROOM
ASEPTIC SUITE
STORAGE
HOUSEKEEPING - STORAGE
MATERIALS MANAGEMENT - IMMEDIATE STORAGE
MATERIALS MANAGEMENT - STORAGE
BEDS - STORAGE
STAFF
LOBBY
FILTER
SAFE AREA
ELEVATORS
OFFICE
WC
COUNSELING ROOM
LAUNDRY - STORAGE
INSTRUMENT ROOM
PREPARATION
DECONTAMINATION
STERILISING
DISPENSARY
STORAGE - CONSIGNMENT/LOANS
STORAGE - STERILE
STORAGE - CASE CARTS
WASTE MANAGEMENT
99.400
7.500
9.400
15.000


L1-01
L1-02
L1-03
L1-04
L1-05
OFFICE 48 m²
PREPARATION 73 m²
STERILISING 73 m²
STORAGE 55 m²
DECONTAMINATION 73 m²
STORAGE 74 m²
BACK OF HOUSE AREAS
EMERGENCY ROOM
ENTRANCE
ADMISSION
SAFE AREA 102 m²
OFFICE 33 m²
STORAGE 56 m²
GIFT SHOP 56 m²
PHARMACY 56 m²
EMERGENCY ROOM ENTRANCE
AMBULANCE ENTRANCE



B
B´
99.400
7.500
7.500
7.500
7.500
7.500
7.500
9.400
7.500
7.500
7.500
15.000
7.500
L2-01
L2-02
L2-03
L2-04
L2-05
AUDITORIUM
212 m²
FOYER
36 m²
STAFF
20 m²
STORAGE
24 m²
STORAGE
24 m²
FILTER
9 m²
CONFERENCE ROOM
177 m²
FOYER
34 m²
OFFICE
27 m²
OFFICE
27 m²
OFFICE
27 m²
OFFICE
27 m²
AUDITORIUM
CONFERENCE CENTER
ADMINISTRATIVE OFFICES
STAFF
8 m²
FILTER
9 m²
SAFE AREA
102 m²
ELEVATORS
FILTER
18 m²
STORAGE
15 m²
STORAGE
24 m²
STORAGE
14 m²
WC
13 m²
KITCHEN
19 m²
FILTER
8 m²
CAFETERIA
ELEVATORS
ELEVATORS
STORAGE
14 m²
STORAGE
24 m²
FILTER
8 m²
FILTER
18 m²
WC
13 m²
ELEVATORS
SAFE AREA
102 m²
OFFICE
38 m²
STAFF
15 m²
FILTER
9 m²
STORAGE
8 m²
ADMINISTRATIVE OFFICES
OFFICE
29 m²
OFFICE
28 m²
OFFICE
28 m²
OFFICE
29 m²
1
2
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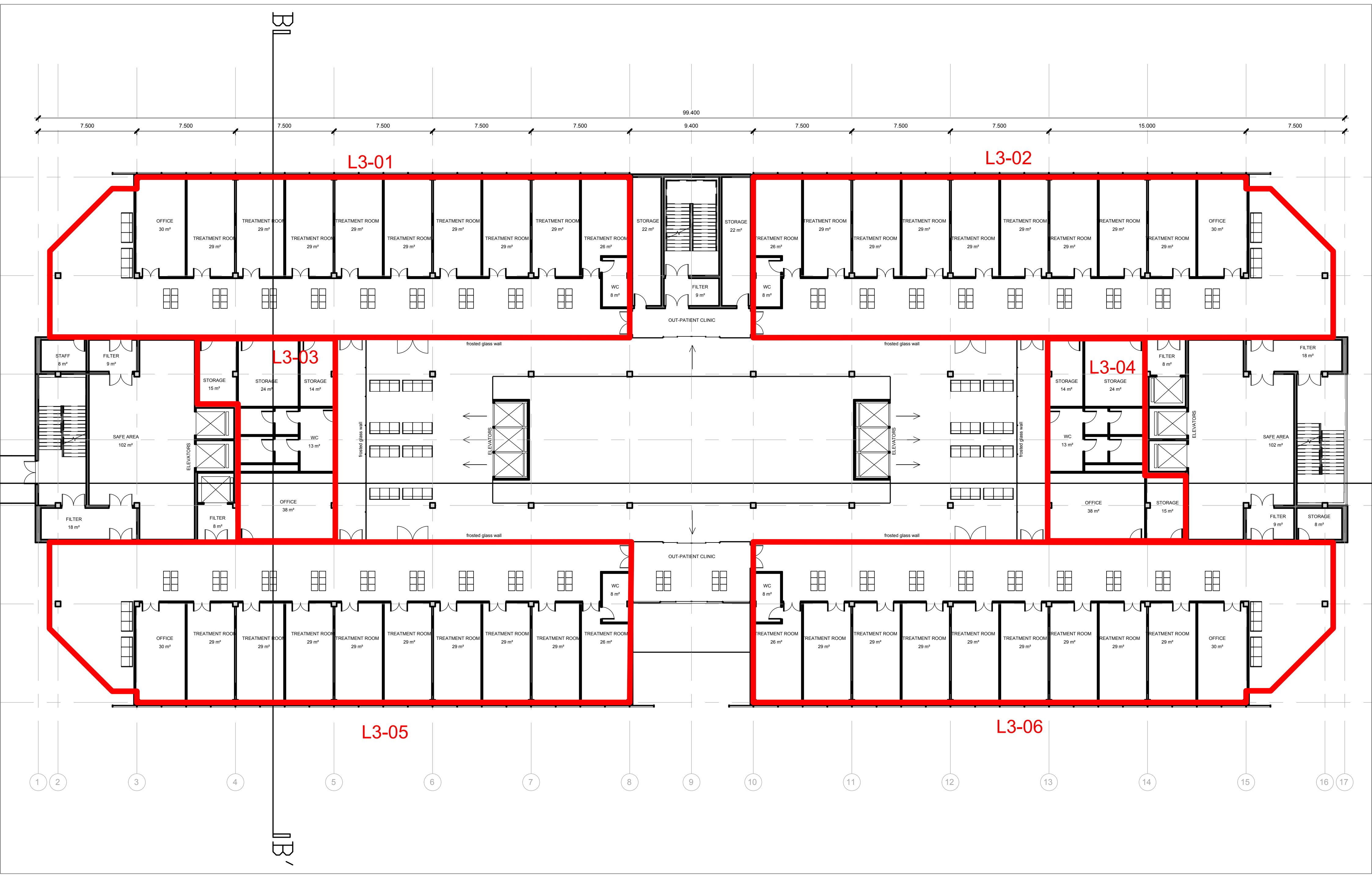
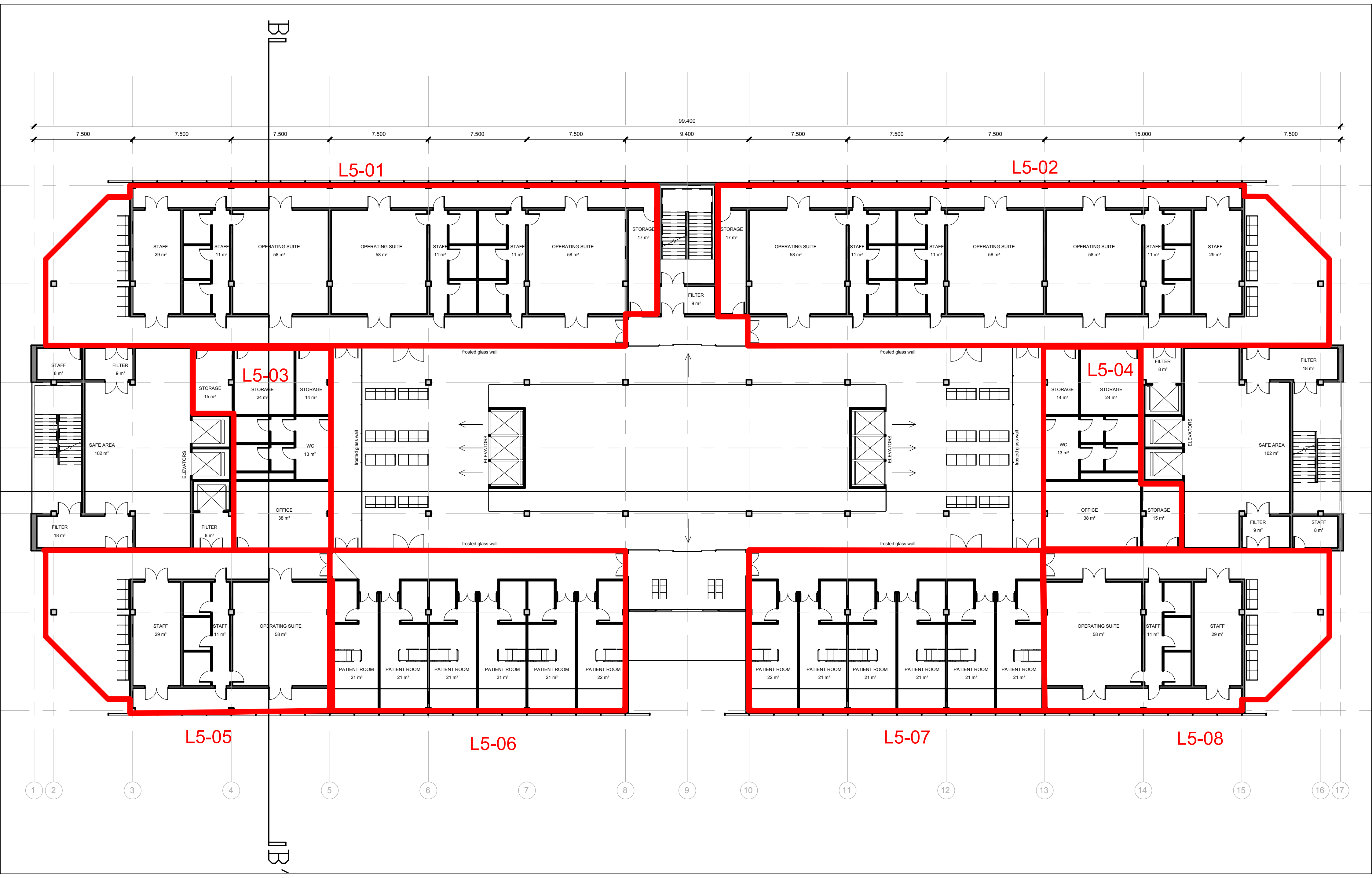
17



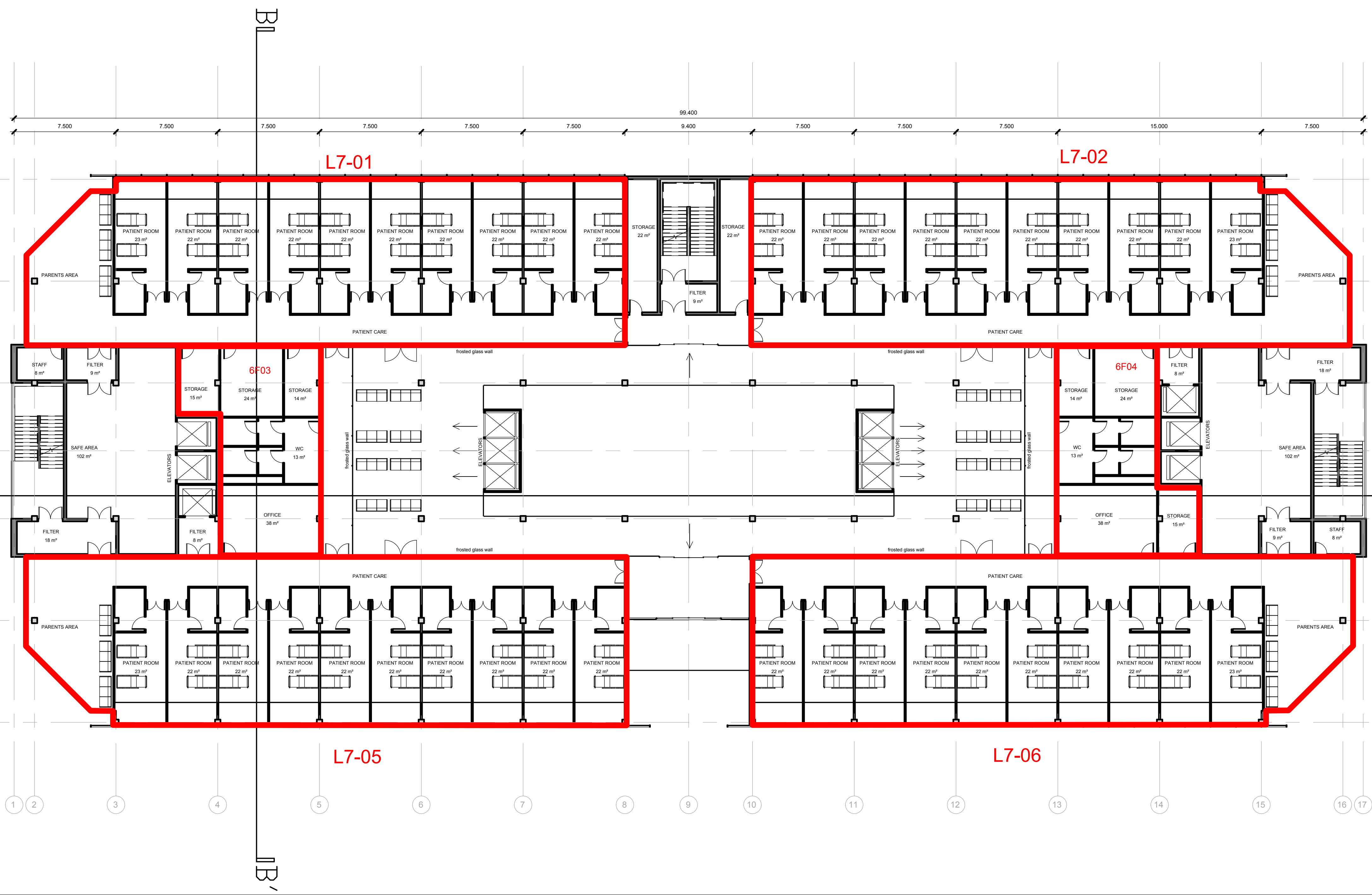
L3-01
L3-02
L3-03
L3-04
L3-05
L3-06
99.400
OUT-PATIENT CLINIC
frosted glass wall
SAFE AREA
102 m²
ELEVATORS

L4-01
L4-02
L4-03
L4-04
L4-05
L4-06
99.400
IMAGING
LABORATORY
SAME DAY SURGERY
PHYSICAL THERAPY
SAFE AREA
102 m²
OFFICE
38 m²
ELEVATORS
frosted glass wall

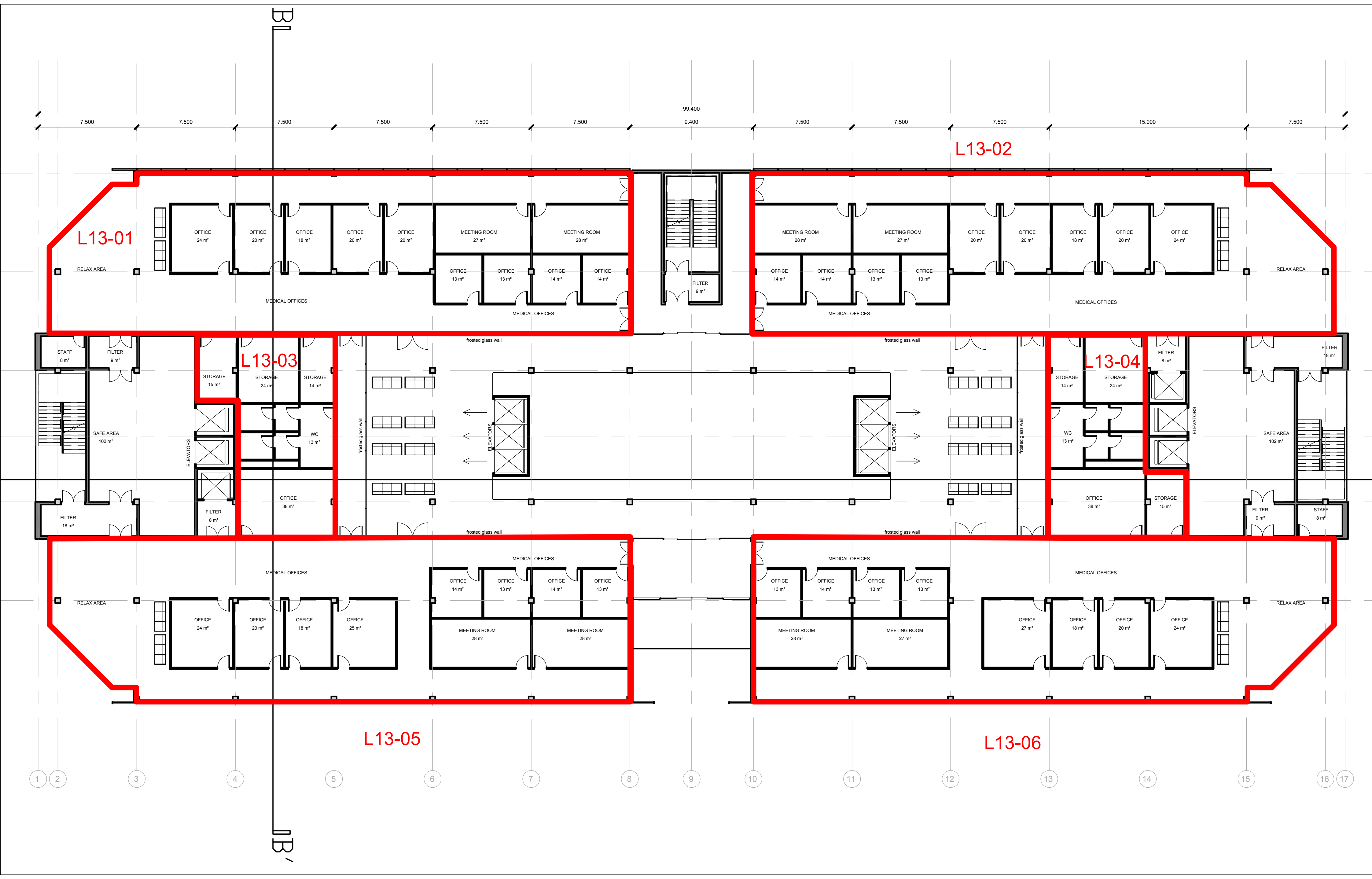


L5-01
L5-02
L5-03
L5-04
L5-05
L5-06
L5-07
L5-08
99.400
7.500
9.400
15.000
OPERATING SUITE 58 m²
STAFF 29 m²
STAFF 11 m²
STORAGE 17 m²
FILTER 9 m²
frosted glass wall
SAFE AREA 102 m²
STORAGE 15 m²
STORAGE 24 m²
STORAGE 14 m²
WC 13 m²
OFFICE 38 m²
FILTER 18 m²
FILTER 8 m²
STAFF 8 m²
ELEVATORS
PATIENT ROOM 21 m²
PATIENT ROOM 22 m²

L6-01
L6-02
L6-03
L6-04
L6-05
L6-06
99.400
BIRTHING UNIT
NEONATOLOGY
PATIENT CARE
OPERATING SUITE
PREP ROOM
ULTRASOUND
PARENTS AREA
SAFE AREA
frosted glass wall
ELEVATORS



L7-01
L7-02
L7-05
L7-06
6F03
6F04
99.400
7.500
9.400
15.000
PATIENT ROOM
PARENTS AREA
PATIENT CARE
STORAGE
FILTER
STAFF
SAFE AREA
ELEVATORS
WC
OFFICE
frosted glass wall
B
B´

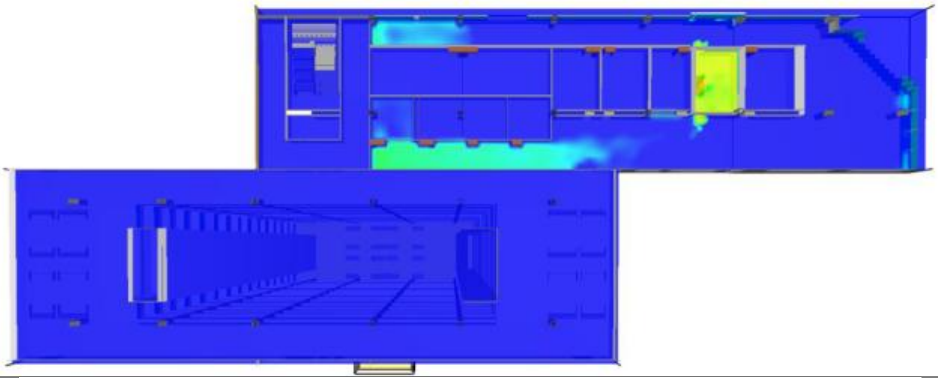
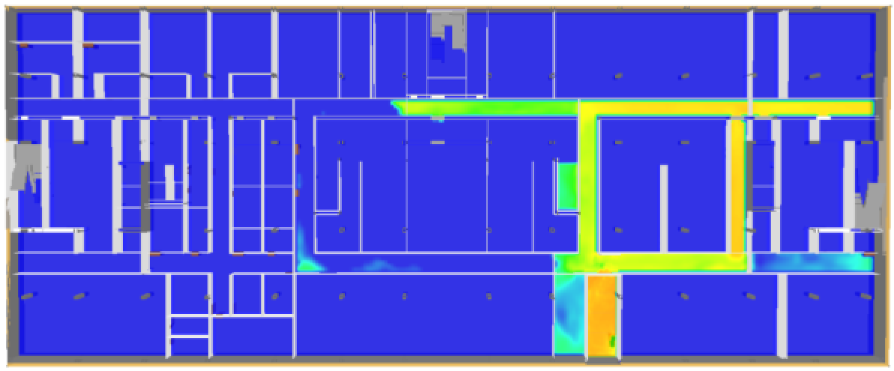
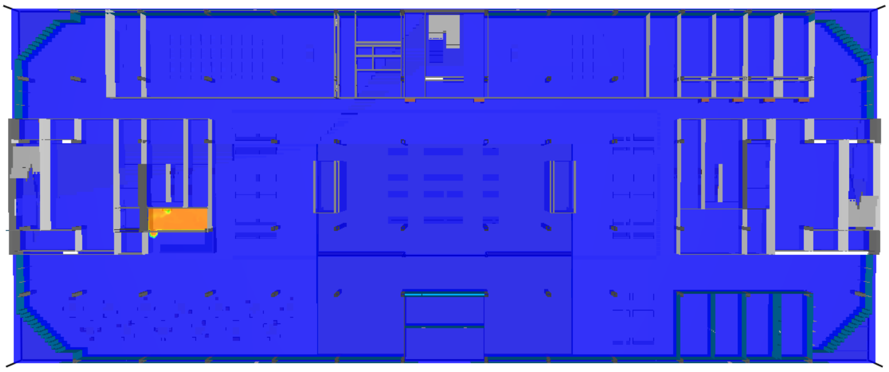
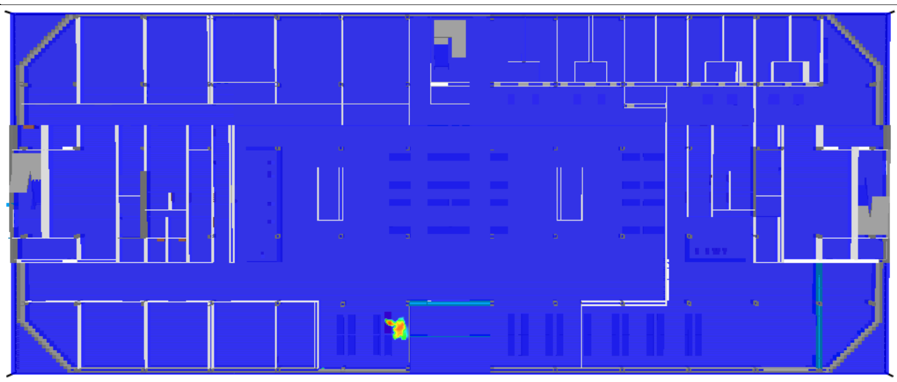
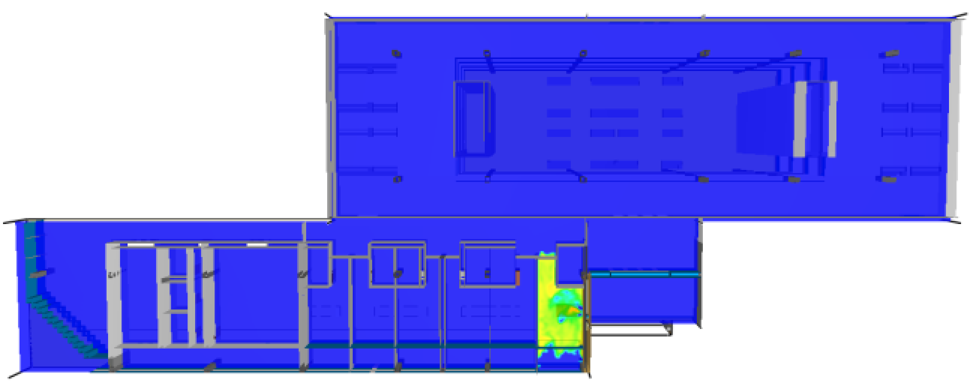


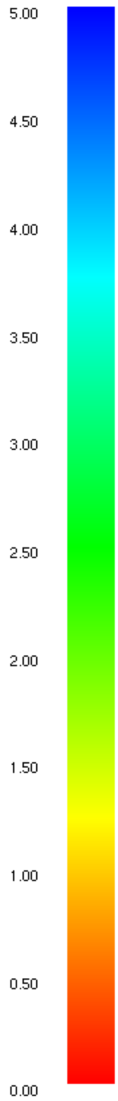
L13-01
L13-02
L13-03
L13-04
L13-05
L13-06
99.400
7.500
9.400
15.000
OFFICE
MEETING ROOM
RELAX AREA
MEDICAL OFFICES
STORAGE
WC
FILTER
STAFF
SAFE AREA
ELEVATORS
frosted glass wall

ANNEX C

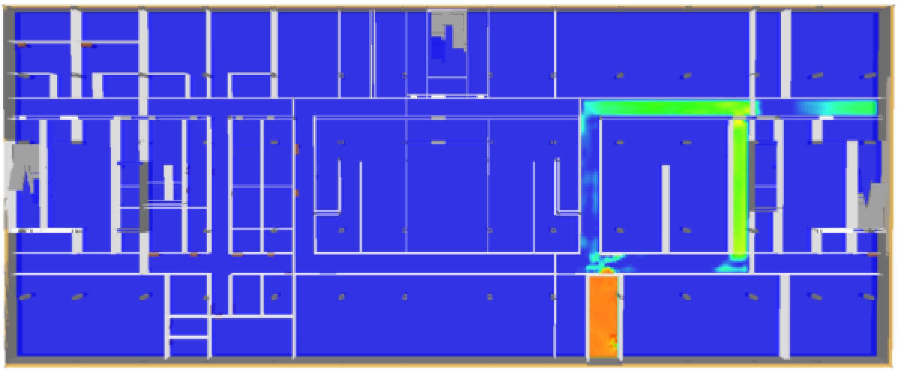
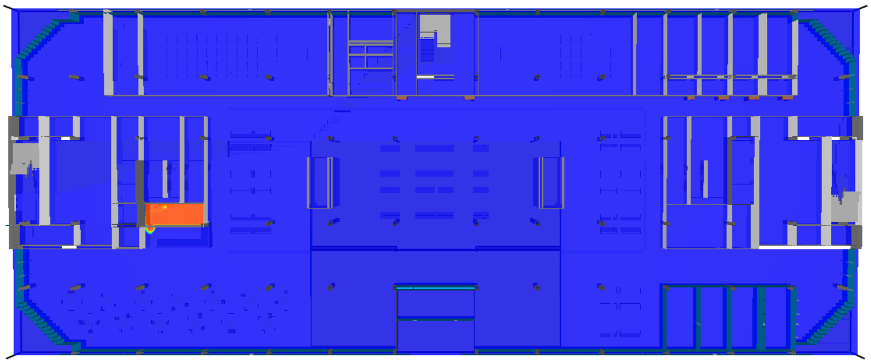
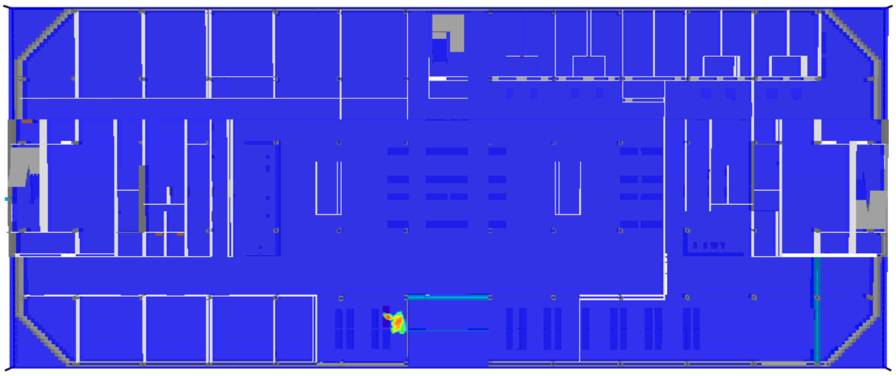
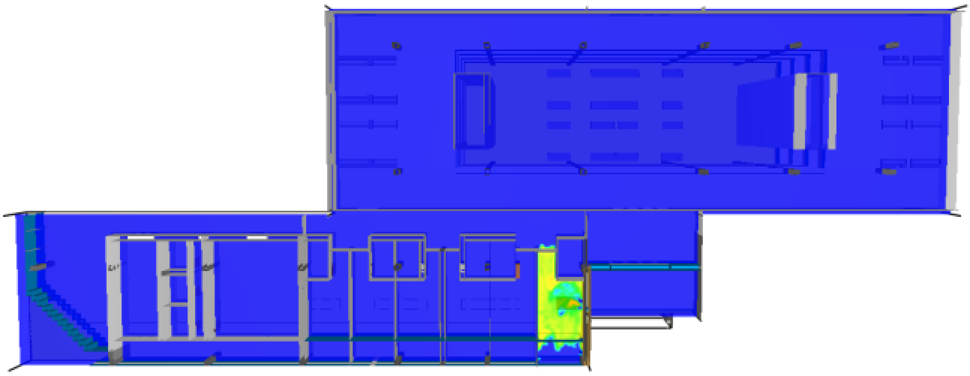
Simulations' results

Visibility [m] for Fire Brigade intervention

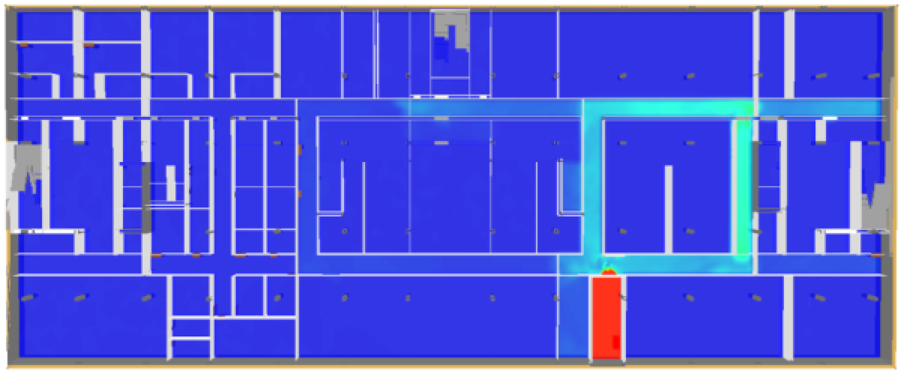
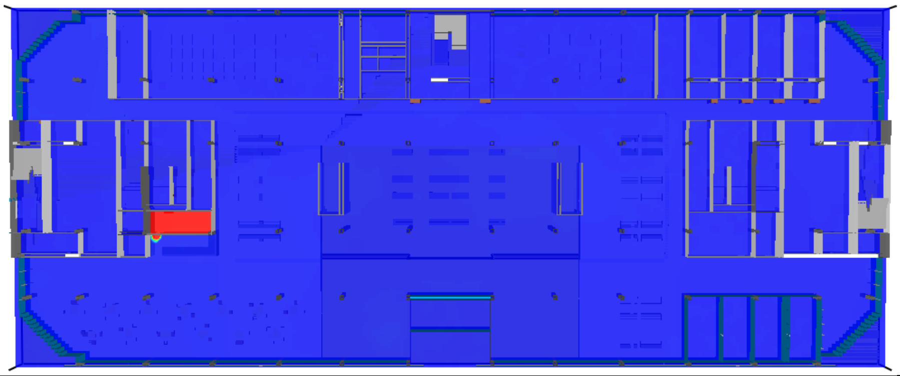
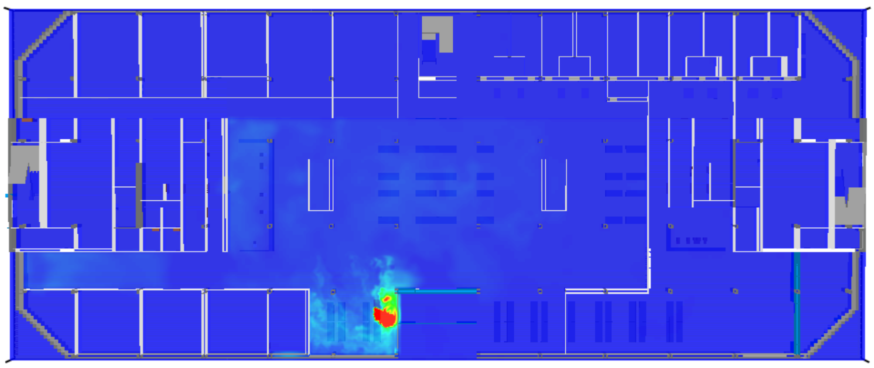
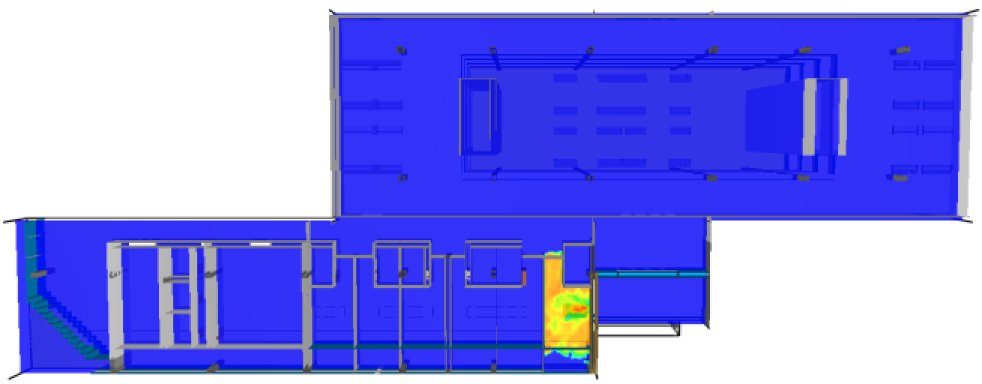
Office Fire at 900 s	
Basement Fire at 900 s	
Kitchen fire at 900 s	
Hall Fire at the HRR peak	
Patient room fire at fire peak	



Visibility [m] for Safe escape of occupants

Office fire at 300 s	
Basement Fire at 300 s	
Kitchen fire at 900 s	
Hall fire at HRR peak	
Patient room fire at fire peak	

Temperature [°C] for Safe escape of occupants

Office fire at 300 s		
Basement Fire at 300 s		
Kitchen fire at 900 s		
Hall fire at HRR peak		
Patient room fire at fire peak		

Temperature [°C] for Fire Brigade intervention