Design of fire safety equivalence of building open arcades to exterior spaces

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ABSTRACT

An arcade is a succession of arches, each counter-thrusting the next, supported by columns, piers, or a covered walkway enclosed by a line of such arches on one or both sides. In warm or wet climates regions, exterior arcades provide shelter for pedestrians. A building open arcade is sometimes called a porch. Arcades usually border a covered section of a building and sometimes they support roofs. They are very old architectural elements that date back thousands of years.

Building open arcades ("Portici") are traditionally employed in cities to provide shelter for pedestrians along public and private streets. Along the closed side of the arcades, commercial activities of all sort often offer their main entrance and exhibition spaces. Other activities as private dwellings or any other kind of civil activity may communicate directly through doors or other openings towards the covered space under the arcade.

According to current prescriptive fire safety regulations, open arcades cannot be considered equivalent to exterior open spaces, and all the activities that have openings towards these covered spaces should be presumed in mutual communication from a fire safety design point of view. In fact, it is hypothesized that closed enclosures allow for the faster spread of fire effluents between the communicating spaces. Nevertheless, according to experiences and engineering judgments, under certain conditions and constraints, the open arcades allow for evacuation of smoke and heat towards the exterior spaces through the open side. When these conditions are met, all the activities that have openings towards these covered spaces could be assumed mutually independent from a fire safety design perspective, because, in case of fire, the fire effluents do not spread easily towards the adjoining activities.

In this paper a fire safety engineering calculation is performed to assess in which circumstances an open arcade can be considered as equivalent to an exterior space for deemed-to-satisfy solutions of the Italian Fire Code (IFC 2015).

The study proposes an arcade parametric fire model, whose pre-processor has been developed in Python, for assessing conditions, safety measures and geometric constraints that allow to recognize building open arcades as exterior safety places. The open arcade can be considered equivalent to exterior space for deemed-to-satisfy solutions when occupants can safely escape from the open arcade towards a safe place, occupants of other activities abutting in the same open arcade are not harmed by the fire effluents coming from the activity involved in the fire, and when fire and its effluents do not spread to other abutting activities. Furthermore, the paper assumes a simplified equivalent model structure of the building arcade where the parametric study conducted with FDS is aimed at setting some basic rules for the fire safety design of building open arcades. The results of the parametric study show that under certain conditions and constraints, the open arcades allow for evacuation of smoke and heat towards the exterior spaces through the open side. Therefore, when these conditions are met, all the activities that have openings towards these covered spaces could be assumed mutually independent from a fire safety design perspective, since in case of an outbreak of a fire the fire effluents do not spread easily towards the adjoining activities.

KEYWORDS:
Open arcades, fire modelling, CFD, Python, exterior safety places
1. INTRODUCTION

To reduce risks and achieve acceptable levels of safety, fire codes and regulations play a fundamental role both in buildings and high hazard facilities. Most of the Italian activities subjected to fire inspection and listed in the annexe 1 of the Decree DPR 151/2011 [1], are subject to prescriptive fire safety codes. These codes are composed of some requirements which try to address all the different components and devices of the system to provide fire safety for a building or an industrial activity. Moreover, when fire safety targets must be satisfied in pre-existing buildings or in activities that are going to be modified into more complex ones, there are more constraints to cope with and it could be difficult to achieve an acceptable level of fire risk using prescriptive-based fire codes and regulations. For these reasons, on August 20th, 2015, the Italian Home Office released the Ministerial Decree of August 3rd, 2015, that contains a new approach to the fire safety design of activities subjected to fire inspection. The technical Ministerial Decree is titled “Approval of fire prevention technical standards, pursuant to Article 15 of Legislative Decree 139 of March 8, 2006” [2], but is commonly recognized among Italian fire officers and practitioners as the Italian Fire Code (IFC) [3].

Following the fire safety engineering principles, the IFC sees the process of the fire safety design considering the system as a whole by focusing on the safety targets whether they are life safety, property loss, business interruption, environmental damage or heritage preservation. The fire design method is very flexible: for each fire-safety project offers design solutions that are semi-performance based (the so-called “deemed-to-satisfy solutions”). These compliant solutions contain prescriptive examples of materials, products, design factors, construction and installation methods, which - if adopted - comply with the performance requirements of the IFC. If a deemed-to-satisfy solution could not be satisfied, the IFC offers performance-based solutions called “alternative solutions”. The alternative solution is any solution that can meet the IFC performance requirements, other than a deemed-to-satisfy solution, using other international fire safety standards, innovative products and fire safety technology and last, but not least, applying the Fire Safety Engineering (FSE) design. In fact, the whole section M (Methods) of the IFC deals with the FSE performance-based approach. The methods M.1 describes the minimum content of the additional fire safety documentation in case of a performance-based approach must be delivered along with the usual design reports (structural, mechanical, etc.), while the sub-methods M.2 contains the guidelines for the identification and the selection of the design fire scenarios to be used for “quantitative analysis”. The last method M.3 contains some details for the application of performance-based approach methods for life safety problems.

According to current prescriptive fire safety regulations, open arcades cannot be considered equivalent to exterior open spaces, and all the activities that have openings towards these covered spaces should be presumed in mutual communication from a fire safety design point of view. Fig. 1 depicts some example of historical building open arcades.

![Fig. 1. Some examples of historical building open arcades](image)

Applying the FSE design procedure of the IFC, this paper proposes an arcade parametric fire model for assessing conditions, safety measures and geometric constraints that allow to recognize open arcades as exterior safety places.

2. IDENTIFICATION OF THE ARCADE FIRE SAFETY GOALS.

The fire safety engineering methodology proposed in chapter M.3 of the IFC is followed. the scope of the following calculation consists in assessing the conditions and the geometric constraints that allow for considering open arcades equivalent to exterior space. The open arcade is to considered equivalent to exterior space for deemed-to-satisfy solutions when the following safety goals are met: occupants can safely escape from the open arcade towards a safe place, occupants of other activities abutting in the same open arcade are not harmed by the fire effluents coming from the activity involved in the fire and fire and its effluents do not
spread to other abutting activities. These safety goals are deemed satisfied if the following performance criteria [4] are respected in any condition:

- the hot smoke layer in the open arcade remains at a height not lower than 2.50 m;
- the same hot smoke layer has an average temperature not higher than 200°C.

No requirement on fire or smoke heat radiation limit is developed, since the temperature of the hot smoke layer implies a radiation level not greater than 2.5 kW/m² and the radiating heat from the burning activity would not be different if the same event had happened in an open space instead of under an open arcade.

Fire resistance rated walls or enclosures are introduced in trial designs to prevent fire and smoke spread towards neighbouring activities through common border elements. The predefined fire scenario for civil activities described in chapter M.2, table M.2-2 of the IFC is employed.

Therefore, a constraint on the typology of the activities abutting in the studied open arcade shall be enforced: only civil activities having a design fire load \( q_f \leq 1200 \text{ MJ/m}^2 \) are allowed abutting in the open arcade. The fire is presumed to have an instantaneous growth to the maximum heat release rate value and an infinite duration. For simplicity, the fire is located directly in the middle of the open arcade.

### 3. GEOMETRY OF THE GENERIC OPEN ARCADE MODEL

By definition, an open arcade is an enclosed space that has at least one of its two longer sides open towards the exterior. The geometry of the generic open arcade is described as in Figure 2, where:

- \( p_z \) is the average height of the vault,
- \( h_a \) is the average height of the opening towards the open space,
- \( p_y \) is the length of the shorter horizontal dimension of the arcade,
- \( p_x \) is the overall horizontal width of the front arcade openings towards the open space, measured at \( h_a \) height, between the end of the arcades or any element that obstacles smoke spread along the open arcade (e.g., fire or smoke curtains).

When multiple openings are present, as in Fig. 2, the value of \( p_x \) shall be obtained by summing the single opening widths, i.e. \( p_x=p_x1+p_x2+p_x3 \). No reduction of the horizontal width of the openings is allowed at heights lower than \( h_a \). The IFC defines the average height of an enclosed space as:

\[
h_{avg} = \frac{\int h \, dA}{A}
\]

with \( A \) area of the enclosed space. The simplified geometrical model of arcades described above takes into account the main parameters that could affect the spread and the accumulation of the heat and smoke under the arcade, namely the average height of the vault \( p_z \) and the average height of the opening towards the open space \( h_a \). Moreover, no description of the occupants quantities, qualities and behaviour is required, because the safe condition for the occupants of the arcade is going to be conserved indefinitely.

### 4. DEVELOPMENT AND EVALUATION OF THE TRIAL DESIGN

Several parametric trial designs are proposed according to the geometry pictured in Fig. 2, and to the following geometric restrictions:

- \( 3 \text{ m} \leq p_y \leq 1.2 \text{ } p_z \),
- \( 0.6 \text{ } p_z \leq h_a \leq p_z \).
Several additional requirements should be applied to construction product elements and materials of other activities abutting in the same building open arcade of the designed activity to prevent fire and smoke spread towards neighbouring activities, as listed in detail in the next Section “5. SELECTION OF THE FINAL DESIGN”.

The evaluation of trial designs is performed by using NIST FDS [5] and a custom parametric preprocessor written in Python [6]. The preprocessor allows the automatic variation of any quantity inserted by the analyst into the FDS input file. The following variations of the parameters are simulated:

- $3 \leq p_z \leq 9$ m,
- $3 \leq h_a \leq 9$ m,
- $3 \leq p_y \leq 10.75$ m,
- $12 \leq p_x \leq 200$ m.

A sensitivity analysis of the model has been also done varying the simulation grid and fire size [7]. Due to the limited space, the results of the sensitivity analysis and numerical conditions are not reported. Trends are extrapolated over the upper limits of the variations. Around 300 numerical fire simulations have been completed in the ranges of variation of the parametric trial design. Some example results are shown in Fig. 4 a) and b).

**Fig. 3.** An example of numerical fire simulation of the modelled open arcade.

**Fig. 4.** Hot smoke layer height results a) and hot smoke layer temperature result b).

Table 1 shows the results of the simulations of the hot smoke layer height for the parametric trial designs, considering $p_x=20$ m and $p_y, p_z$ and $h_a$ varying according to the trial design range. The fluctuating in time-height value is averaged after the studied system has reached stationary conditions at around 120 s of each simulation.

The empty cells represent out-of-allowed-bounds geometric conditions. It is important to underline that results displayed in italics are not respecting performance criteria: the hot smoke layer in the open arcade is lower than 2.50 m or it has an average temperature higher than 200°C. The hot smoke layer temperatures for the parametric trial designs calculated during the simulation, as averaged after the studied system has reached stationary conditions at around 120 s of simulation, are all under 200°C thus respecting the assumed performance criteria. Local temperature on structural elements in the vertical of the fire plume are significantly higher, and could lead to localized collapse of the open arcade, if not specifically designed as fire-resistant construction product elements.
Table 1. Hot smoke layer average height LH, after achieving stationary conditions at 120 s for px=20.00 m

| px [m] | py [m] | pz [m] | ha [m] |
|--------|--------|--------|--------|
| 3.00   | 3.00   | 3.00   | 3.00   |
| 3.00   | 3.50   | 3.25   | 3.50   |
| 4.00   | 4.00   | 4.00   | 4.00   |
| 4.00   | 4.00   | 4.00   | 4.00   |
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7. smoke barriers classified at least D 30 according to EN 12101-1 [8], closing the entire py dimension of the open arcade and descending to the lower height of the hot smoke layer, in other cases.

Fig. 5 resumes the 1 to 7 aforementioned requirements for construction product elements of the building open arcades that have to be fulfilled for considering them as an open safety place.

Fig. 5. Building open arcade construction product elements requirements for considering an open arcade as an open safety place.

CONCLUSION

According to current prescriptive Italian fire safety regulations, building open arcades cannot be considered equivalent to exterior open spaces, and all the activities that have openings towards these covered spaces should be presumed in mutual communication from a fire safety design point of view. The study proposes a building arcade parametric fire model, whose pre-processor has been developed in Python, that is used for assessing conditions, safety measures and geometric constraints that allow to recognize open arcades as exterior safety places. Under certain conditions and constraints, the open arcades allow for evacuation of smoke and heat towards the exterior spaces through the open side. When these conditions are met, all the activities that have openings towards these covered spaces could be assumed mutually independent from a fire safety design perspective, because, in case of an outbreak of a fire, the fire effluents do not spread easily towards the adjoining activities. Moreover, this paper is an example of a simple method to build deemed-to-satisfy solutions for inclusion in prescriptive fire safety codes that are fully justified by quantitative methods and are not based on “magic numbers” [9].

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