NUMERICAL-SIMULATION RESEARCH ON BUILDING-FACADE GEOMETRY AND ITS EFFECT ON FIRE PROPAGATION IN WOODEN FACADES

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ABSTRACT: Fire protection is a very important requirement in the facade of a building. When there is a fire in a building, the facade can be one of the quickest spreading pathways, regardless of the material of which it is constructed. Therefore, in terms of safety, the study of mechanisms controlling the spread of fire through the facade is an issue that needs to be addressed, especially when it involves combustible material claddings such as wood. In several European countries the building regulations restrict the use of combustible materials in facade claddings. The application of passive protection measures to control the spread of fire would help minimize such restrictions.

In this research it was used computer-simulation techniques to study the behaviour of flames ejected through the windows on wooden facades. We studied five wooden facade systems which combine different configurations of windows, eaves and non-combustible elements which act as fire barriers. The results showed the strong influence of geometrical configuration of the facade elements in controlling fire spreading. They also show that it is possible to establish an acceptable standard of fire protection through non-combustible elements that does not alter the aesthetics of wooden facades.

The study was performed using field models of computational fluid-dynamics. Particularly through the software: Fire Dynamics Simulator (FDS) to solve numerically the mathematical integration models, PyroSim for the graphical interface, and Smokeview for viewing the results.

KEYWORDS: Combustible cladding, fire dynamics simulator, fire performance on facade, flame spreading control, wooden facades, configuration of the facades.

1 INTRODUCTION

Wood is a natural material with great features. It is versatile, resistant, light and aesthetically pleasing. Moreover, wood is an ideal choice from environmental point of view and human health. This material has been part of the building tradition in different countries. For several decades, its use was relegated by other building materials such as concrete, steel or aluminium. However, Wood has recovered its importance in the construction industry throughout the last years.

Nowadays, its added value lies not only in their optimal constructive properties, but also for its qualities as a natural material, recyclable and with low environmental impact. A more widespread use of wood in construction is perceived as a good way to achieve environmental goals within the construction industry.

Nevertheless, the combustibility of timber is one of the main obstacles for it to be widely used in the construction sector, especially as a facade cladding. In the most of the building regulations of European countries the use of wooden claddings is limited to a buildings of two or three storeys. In some cases, the regulations and standards limit the percentage of the total surface of cladding that doesn’t meet the required reaction to fire classification: B-s3,d2

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(according to the European harmonized classification), that is to say a material with a low contribution to fire, while the wood-based panels and timber components are classified as D-s2,d0 which indicates that it is a material with a high contribution to fire.

In recent years, there have been several studies conducted in countries with a long tradition in timber construction, such as Switzerland [1], Germany [2] or Finland [3]. The results have shown that research is essential to find appropriate fire protection solutions, also in some cases, to reduce the constraints imposed by building regulations regarding fire safety.

In the case of Switzerland, a series of researches and large scale tests have been the basis for the regulation for fire safety in wooden buildings (2005) which nowadays serves as a model for other countries in the region. This regulation allows the construction of wooden buildings for up to six floors. The Swiss regulation also allows the construction of facades with combustible materials for buildings up to eight floors.

2 BACKGROUND

According to different experts, the fire spreading through the facade is one of the most common and dangerous spreading pathways in a building [4, 5]. The risk increases significantly in the case of the facades with combustible claddings [3], given that the heat flux intensity and speed of fire spreading may be higher. Moreover, the fire spreads not only vertically as normally occurs, but also spreads horizontally due to the flammability of the cladding material.

Although wood is highly fire resistant when it is used in structural elements with large sections. It is a combustible and flammable material, therefore it has a weak fire performance when is used in thin sections. Usually, the wooden facades are made up of thin boards or small elements arranged in strips, planks, tiles, etc (Fig.1).

Therefore, the fire behavior of a wooden cladding is mainly defined by its combustibility. The carbonization of the cladding pieces does not have a significant effect in limiting the spread of fire. The burning rate of a wooden facade depends on the species of wood, its density and moisture level, as well as the type and arrangement of the cladding elements (Fig. 2).

Two options must be taken into account to limit the risk of fire spread through wooden facades:

- Flame retardant treatments to improve the reaction to fire performance of the cladding material.
- Elements of construction to avoid the contact between the fire plume and combustible cladding and deflector elements with the ability to change the flames trajectory and prevent its passage through the claddings.

This study is focused in the second option.

3 FIRE SPREADING THROUGH THE FACADES

An event of fire through the facade may originate from outside the building, due to hot coals, either by a fire in a nearby building or a wooded area in flames. Also by an element that burns in the front of the facade (garbage container, furniture, etc.). But the most dangerous situation and statistically the most frequently is the fire originated in a compartment of the building which spreads outwards through the windows. This study is focused only in this last case.

When there is a fire in a building the façade can be one of the quickest spreading pathways. The fire could affect not just the building where the ignition is produced but also the nearby structures. In this area of the building there are many factors that facilitate the dynamics of fire, such as: the unlimited amount of oxygen, the verticality of the surface, the pressure difference between inside and outside of building, the wind, etc. Therefore, the vertical spread of fire occurs even when the cladding materials of the facade are non combustible, but the risk increases in the case of the facades with combustible claddings [3-5]. The heat flux intensity and speed of fire spread may be higher. Moreover, the fire spreads not only vertically, as normally occurs, but also spreads horizontally due to the flammability of the cladding.

![Figure 1: Some types of horizontal timber claddings. a) Overlapping b) Wood Shed c) Tongue and groove.](image)

![Figure 2: Classification of type of cladding depending on the influence on fire spreading [1].](image)
Since the 60s, several authors have conducted research related to fire plume projecting from fire compartment windows. All this research has set up a substantial base of knowledge on this subject. Over time these studies have provided more detailed information regarding the incidence of heat flux on the exposed surface, the trajectory of the flames and the influence of different factors on the fire spreading, such as: the heat release rate (HRR) and geometry of the fire compartment, the geometric configuration of the facades and windows, the characteristics of the facade cladding material, etc [10].

4 INFLUENCE OF THE GEOMETRICAL CONFIGURATION

The influence of the geometric factor on fire propagation through the façade has been studied by many authors. The design elements of the facade could have a positive or negative effect on fire spreading, depending of its size and location respect to the windows. Vertical outgoing elements can channel the fire facilitating its spread, while horizontal projections as eaves or balconies acts as deflectors which divert the trajectory of the heat flux, minimizing the thermal exposure and flames incidence on the facade surface [6-7-8].

The HRR of the fire compartment together with the size and shape of windows have a great influence in the trajectory and shape of the fire plume, as well as in the heat flux density [9-10].

5 OBJECTIVES

This study is devoted to measures of passive fire protection based on the design of the facade. The study aims to assess the influence of some geometric factors of the facade on the fire propagation through the facade. The main objective is to assess the level of protection provided by horizontal projection elements (eaves) and non-combustible bands. Also we analyze the influence of the windows size.

6 METHODOLOGY

This research is conducted using field models of computational fluid-dynamics to evaluate some aspects of fire dynamics in the different cases studied, the conditions of which are explained below. In particular, the following software is used: The Fire Dynamics Simulator (FDS) to solve the models PyroSim for the graphical interface, and Smokeview to visualize the results. Computer-simulation is a useful tool that provides an approach to the problem of fires, taking into account different variables and scenarios. One of the great advantages of simulation is the possibility to study some aspects of the phenomenon of fire without incurring the high costs of laboratory tests.

In this research a scenario representing a fire in a living room is considered. The fire starts on a couch in the ground floor of the scenario. To achieve this, an ignition source of 400 cm² is placed on the surface of the couch. This source is characterized by a burner with a heat release rate of 1000 kW/m². Once the fire reaches the stage of flashover, it spreads to the outside through the windows. The windows are disabled when a device (heat detector) reaches 300°C. Moreover, the window frames are disabled when a device (heat detector) reaches 500°C (Considering a failure in the aluminium window frames due to fire exposure) as a result fire enters to the cavity. Fire growth occurs according to the calculation performed by the software. The FDS solves the equations governing the simulated system and provides graphical and numerical data for each scenario. The models show a simplified representation of the analyzed cases.

Nine cases are evaluated based on a common computational domain and a fire scenario. Table 2 describes the variables considered in each case under study. The characteristics of the computational domain and the scenarios are described below.

6.1 COMPUTATIONAL DOMAIN

The table 1 shows the simulations parameters. The characteristics of the computational domain are as follows:
- The grid size is 6.50x4.90x8.25 m.
- Each cell has a uniform size (0.10 m x 0.10 m x 0.10 m). The total number of cells in each domain is 241,920.

There are two different areas to be considered in the domain (Fig.3a):
A. Enclosure (internal scenario)
B. Open (external scenario)

Figure 3: Computational domain - three-storey scenario
a) General configuration and contents
b) Geometric configuration of de façade case 4 according to Table 2.
6.2 GEOMETRIC CONFIGURATION AND CONTENTS OF THE SCENARIO

The scenario consists of a three-storey living space of 4.00 x4.90m. Each floor is 2.50m high and is separated by concrete floors (noncombustible material). The scene contains typical living room furniture. The characterization of the materials that constitute this furniture is based on some parameters that have been extracted from the database of Ref. [11]. This scenario is representative of a typical living space with a fire load density of 600 MJ/m².

The gate located at the back of the scenario ensures a steady supply of oxygen and a mild current of forced ventilation. The simulation parameters in all study cases are the same (Table 1). Variables only apply to the elements forming part of windows as shown in Fig. 4c and table 2.

### Table 1

<table>
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<th>Parameters of simulations</th>
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<td>Temperature</td>
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<td>Moisture</td>
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<tr>
<td>Ventilation conditions</td>
<td>Moderate wind</td>
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<td>Simulations time</td>
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</table>

### Table 2

<table>
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<th>Horizontal projection</th>
<th>Bands</th>
<th>Windows</th>
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<td>Variable 2 Length</td>
<td>Variable 3 Width</td>
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</table>

6.3 MEASUREMENT DEVICES

Data on the evolution of the temperatures are recorded through thermocouples located at the height of the parapet of the first floor (Fig.4a). In order to observe the distribution of temperatures in certain areas of the scenario, chromatic planes of two dimensions are used, as seen in Figure 6.

6.4 THE FACADE

The facade consists of an exterior cladding yellow pine and an interior wall covered with plasterboard. The model used for the simulation does not detect details smaller than the control cells of the computational domain; therefore the model assumes the facade cladding as a continuous and smooth surface without slats.

The main purpose of the study is to explore the ability of certain facade elements to control the spread of fire. Specifically, it aims to determine the level of protection provided by elements as:

- Horizontal projections (aprons) of noncombustible material.
- Bands of non-combustible cladding on the sides of the windows.

6.5 DETAILS OF WINDOWS

The detail (Fig.5) consists of a concrete lintel whose depth and length are variable depending on each case. This element prevents the passage of fire into the ventilated chamber (in the case of ventilated facades) and also acts as a deflector that changes the vertical trajectory of flames projecting through the windows. The sill is also a concrete element, but its size is the same in all the cases. Using concrete elements is possible ensure its stability to fire. Usually, lintel and sill are the more affected elements in this kind of fire spread. In order to prevent the horizontal fire spread noncombustible bands were placed on the sides.
of the windows (panels with sheets of steel or aluminum), in this way is avoided contact of the flames and the combustible cladding. The objective is to determine the proper depth and length of the horizontal projections and side strips. Table 2 shows the study cases considered. In each case combine different options in relation to the four variables described in Fig.4.

7 RESULTS

The results show the great influence of the geometric factor of the façade on external fire spread.

7.1.1 Depth of the horizontal projections

- **Small windows**
  
  The temperature distribution graphs show that the horizontal projections deflect the trajectory of the flames outwards, preventing the incidence of heat flux on the facade. The greater the depth of horizontal projection, the less is the probability of vertical fire spread (Fig.6). The horizontal projection of 15 and 30 cm slightly deflect the trajectory of flames, which may be insufficient to prevent the spread of fire through the cladding, taken into account that the ignition temperature of wood is around 320ºC. A horizontal projection of 60 cm or more effectively reduces the incidence of heat flux on the surface of facade.

- **Large windows**
  
  This aspect was studied in the case of larger windows. According to results, the size of windows is an important factor to consider in controlling fire spread through the facade. The size of the flames and the amount of heat flux emitted is proportional to size of windows through which are projected (Fig.8a-b). According to the graphs of
temperatures the difference between the horizontal projections of 15, 30 and 60 cm is less clear in the case of large windows. A larger horizontal projection may be necessary when the facade openings (windows, doors) are big. For example an apron or balcony of 80cm can be a good option to significantly reduce the heat flux on the surface (Fig.7).

The fig.8 reproduces the Heat Release Rate (HRR) in the compartment fire for the two cases: with small windows (1.50x1.0m) and large windows (1.50x2.10m). These curves show that the window size significantly influences the evolution of the fire in the enclosure. In the room with small windows the fire development is a bit faster, but in the room with large windows the fire is considerably more intense.

![Figure 8: (top) Graphics of fire spreading through the facade at time of 400 s (a) small windows b) large windows. (bottom) Comparative of HRR of the two windows sizes.](image)

7.1.2 Length of the horizontal projections

The results show a dual effect on the arrangement of these elements, one positive and one negative. The longer the horizontal projection, the less is the facade area exposed to the heat flux and flames, in particular, the surface which is just above the horizontal projection Fig.9. Moreover, temperature distribution graphics show that the fire can scroll to the edges of the projecting element, affecting other areas of the facade. Fig.10. This behavior is due to the fire tends to take the shape of the surface by which it spreads.

![Figure 9: Comparative of temperatures between eaves with three lengths for thermocouple 2. Scenarios with small windows](image)

7.1.3 Bands of non combustible material on the sides of the windows

The comparative of temperature distribution on the external wall show a significant reduction in heat flux over the area coated with the band of 60 cm. The bands of 15 and 30 cm are considered insufficient to limit the risk of horizontal spread of fire Fig.11.

![Case 1 (15 cm) vs Case 2 (15 cm)](image)
8 CONCLUSIONS

This study has examined a particular geometry of facades with combustible claddings. The results are limited to the examined geometry. The results showed that the building façade geometry can greatly impact the behavior of fire and its propagation. Horizontal projections of more than 60 cm are required to deflect the trajectory and shape of the fire plume. However, projections greater than 80 cm are appropriate to reduce the heat flow on the surface of the façade when the risk is greatest, for example due to the size of the windows. The windows size is an important issue in the fire spread control through the facades. Small windows reduce the risk of spread because the emitted heat flux is lower in comparison to large windows.

The length of the horizontal projections deserves to be studied more broadly, even including different wind conditions.

Horizontal bands of 60 cm of noncombustible material located on either side of the window openings can be a good measure to reduce the risk of horizontal fire spread, which is usually associated with the facade combustible claddings.

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Figure 10: Comparative of temperatures between different cases at time of 500 s Front view.